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THESIS

MUOS: APPLICATION IN NAVAL HELICOPTER OPERATIONS

by

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March 2015

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13. ABSTRACT (maximum 200 words)

The Mobile User Objective System (MUOS) is the next generation of military satellite communications technology. Using a unique combination of satellite vehicles and radio access facilities, MUOS allows the end user unparalleled access to the global information grid (GIG) with a significant increase in voice and data capacity over legacy UFO systems. Leveraging current WCDMA technology used by commercial cellular companies, the MUOS system will allow uninterrupted communications worldwide.

This research aims to identify gaps in existing naval helicopter network capabilities and how to apply MUOS to further increase operational effectiveness. Current and legacy helicopter platforms were analyzed regarding connectivity in a network centric environment. Using simple modeling techniques in order to reduce the throughput of the user terminal to 16 kbps enabled a simulation of load times of various Internet applications.

Analyzing the load times of web applications gives an initial indication of the viability of MUOS in the rotary wing environment. Even when reduced to a throughput of 16 kbps, many of the applications would still be usable in benign flight regimes. Text- or chat-based applications will see the biggest benefit from MUOS technology, allowing aircrews to quickly disseminate information anywhere in the world.

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MUOS: APPLICATION IN NAVAL HELICOPTER OPERATIONS

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The Mobile User Objective System (MUOS) is the next generation of military satellite communications technology. Using a unique combination of satellite vehicles and radio access facilities, MUOS allows the end user unparalleled access to the global information grid (GIG) with a significant increase in voice and data capacity over legacy UFO systems. Leveraging current WCDMA technology used by commercial cellular companies, the MUOS system will allow uninterrupted communications worldwide.

This research aims to identify gaps in existing naval helicopter network capabilities and how to apply MUOS to further increase operational effectiveness. Current and legacy helicopter platforms were analyzed regarding connectivity in a network centric environment. Using simple modeling techniques in order to reduce the throughput of the user terminal to 16 kbps enabled a simulation of load times of various Internet applications.

Analyzing the load times of web applications gives an initial indication of the viability of MUOS in the rotary wing environment. Even when reduced to a throughput of 16 kbps, many of the applications would still be usable in benign flight regimes. Text- or chat-based applications will see the biggest benefit from MUOS technology, allowing aircrews to quickly disseminate information anywhere in the world.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADDS	Aviation Digital Data Service
ALFS	Airborne Low Frequency Sonar
ASTAC	ASW/ASuW Tactical Air Controller
ASuW	anti surface warfare
ASW	anti submarine warfare
ASWCS	anti submarine warfare combat system
BLOS	beyond line of sight
C2	command and control
CDL	common data link
CG	guided missile cruiser
CONOPS	concept of operations
CONUS	continental United States
COP	common operational picture
CSAR	combat search and rescue
CSG	carrier strike group
DAMA	demand assigned multiple access
DD	destroyer
DDG	guided missile destroyer
DICASS	directional command activated sonobuoy system
DIFAR	directional frequency analysis and recording
DISA	Defense Information Systems Agency
DISN	Defense Information Systems Network
DOD	Department of Defense
EHF	extremely high frequency
ESM	electronic support measures
FFG	guided missile frigate
FLIR	forward looking infrared
FLTSAT	fleet satellite system
GIG	Global Information Grid
HADR	humanitarian assistance disaster relief

HC	Helicopter Combat Support Squadron
HF	high frequency
HSC	Helicopter Sea Combat Squadron
HSL	Helicopter Anti-Submarine Squadron Light
HSM	Helicopter Strike Maritime Squadron
ISAR	inverse synthetic aperture radar
ISR	intelligence, surveillance, and reconnaissance
JREAP	Joint Range Extension Application Protocol
JWICS	Joint Worldwide Intelligence Communications System
LAMPS	Light Airborne Multipurpose System
LOFAR	low frequency analysis and recording
LOS	line of sight
MAD	magnetic anomaly detector
MEDEVAC	medical evacuation
MIDS-LVT	Multifunctional Information Distribution System–Low Volume Terminal
MIL-STD	military standard
MILSAT	Military Satellite Communications System
MTS	Multi-Spectral Targeting System
MUOS	Mobile User Objective System
NAVAIR	Naval Air Systems Command
NCTAMS	naval computer and telecommunications area master station
NIPRnet	Non-secure Internet Protocol Router Network
NOTAM	notice to airmen
NSW	naval special warfare
NVD	night vision device
OSPF	open shortest path first
OTH	over the horizon
PCOSI	point and click operator interface
RADAR	radio direction and ranging
RAF	Radio Access Facility
RF	radio frequency

SAR	search and rescue
SA-WCDMA	spectrally adaptive wideband code division multiple access
SATCOM	satellite communications
SIPRnet	Secure Internet Protocol Router Network
SHF	super high frequency
SOF	special operations forces
TCP/IP	Transmission Control Protocol / Internet Protocol
TDMA	time division multiple access
TTP	tactics, techniques, and procedures
UHF	ultra high frequency
UFO	UHF Follow-On
USNS	United States Naval Ship
VERTREP	vertical replenishment
VHF	very high frequency
VLAD	vertical line-array DIFAR
VOIP	voice over internet protocol

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I. INTRODUCTION

A. BACKGROUND

Data requirements on the modern battlefield have increased substantially over the last century. Data takes many forms, to include voice, text, imagery, and recently full-motion video. The ability to get this information to the warfighter and the decision makers located in the operation centers around the globe requires a network that is agile enough to operate in an austere environment and small enough to reach the edges of the battle space. The Mobile User Objective System (MUOS) is the next generation satellite-based network communication technology to assist the warfighter in their efforts.

The Naval Helicopter community has recently incorporated Link 16 and satellite communications (SATCOM) into the operational environment with the introduction of the MH-60R/S helicopters. This technology has opened up new paths of information and data flow that were previously unavailable to helicopter aircrews. The Helicopter Strike Maritime (HSM) and predecessor Helicopter Anti-Submarine Light (HSL) community has had data link capability in the form of Hawklink but needed a Light Airborne Multipurpose System (LAMPS) capable ship to act as the intermediary into the battle group network. The Helicopter Sea Combat (HSC) community is new to the data connected environment with the addition of Link 16 capability, but there are gaps not covered by Link 16 with regards to working with small units and ground personnel unable to access Link 16 data. Both Hawklink and Link 16 do not allow the operator to access the Defense Information Switching Network (DISN), which is synonymous with NIPRnet and SIPRnet to the end user.

MUOS allows aircrews to access the Global Information Grid (GIG) from anywhere in the world using spectrally adaptive-wideband code division multiple access (SA-WCDMA) technology. This technology is better known in the communication field as 3G cellular technologies, but has been modified to meet military specifications.

B. PURPOSE

The purpose of this thesis is to explore emerging technologies such as MUOS and the application of MUOS in the rotary wing operational environment. The ability of aircrews, ground, command and control (C2), and intelligence personnel to exchange information worldwide through access to the GIG will increase mission effectiveness of the naval helicopter community primary mission areas. Planners and command centers associated with Personnel Recovery, Humanitarian Disaster and Disaster Relief (HADR), and medical evacuations (MEDEVAC) may be able to use MUOS technology to increase the response time and prioritize appropriate assets in the field. The ability to conduct administrative tasks inflight will also increase air and ground crew situational awareness and efficiencies.

User interface plays a critical role in the application of new technology. Current cockpit technology is limited by a user interface that requires a lot of heads down time to interact with the aircraft network systems. Naval Air Systems Command (NAVAIR) has recently acknowledged a need for a better user interface in the cockpit with the release of a point and click operator system interface (PCOSI) upgrade to MH-60R/S helicopters to enhance the efficiency of aircrew interactions with the system (Lockheed Martin, 2011). MUOS can leverage current TCP/IP and tablet technology to exploit the familiarity of these graphical user interface systems with aircrews and possibly establish the viability of MUOS beyond a voice-only satellite communication link and explore its relevancy to the existing information exchange.

C. RESEARCH QUESTIONS

The following questions will be addressed in this thesis:

1. Is current naval helicopter network capability sufficient?

2. Are there gaps in information flow that degrade mission effectiveness?

3. Is MUOS a viable network in rotary wing aviation?

4. Can existing TCP/IP technology be leveraged to enhance situational awareness across all aspects of Naval Helicopter operations?

D. METHODOLOGY

A qualitative approach is used to determine the effectiveness of MUOS in helicopter operations. Review of case studies of current tactics, techniques, and procedures (TTPs) and an analysis of after action reports of actual operations conducted in selected mission areas represents the majority of this research. While researching where MUOS could be effective within the current TTPs, conversations with experienced aircrews to explore various ways to leverage this new technology were undertaken.

A simple simulation consisting of restricting the throughput to a terminal as proposed by the current concept of operations (CONOPS) via software, will allow for testing the feasibility regarding likely data requirements requested by aircrews. The lack of operational terminals limited the ability to test the system real time in actual scenarios.

Primary data sources will include technical literature provided by various vendors associated with MUOS through internal testing. This data will then be scrutinized to validate whether MUOS could be a viable data platform for naval helicopter operations in addition to “voice only” communications like current SATCOM technology.

E. SCOPE

The scope of this research will be limited to legacy naval helicopter platforms, current SATCOM systems, and MUOS itself. By researching early adoptions of both network connected helicopters and SATCOM systems of the past, we can trace the increase in demand. The fundamental understanding of MUOS is critical to this research and will be discussed. This will allow for the exploration of MUOS with respect to naval helicopter operations and provide a better understanding of the benefits over current beyond line of sight (BLOS) communication networks.

F. BENEFITS OF STUDY

The benefits associated with global reach back of using an IP-based network will result in better situational awareness for both aircrew and C4I nodes. The ability to share information located in an operation center with aviation assets may allow for the reduction of redundant systems such as blue force tracker. The application of MUOS in conjunction with the Joint Range Extension Application Protocol (JREAP) could allow for Link 16 information to be passed beyond line of sight (BLOS) without the addition of an airborne relay asset.

A limitation associated with this research was the lack of hardware terminals at the operator level. This limitation affected the ability to validate various concepts through operational testing either in a simulated environment or in air testing.

At the conclusion of this research data should be available to assess the viability of the MUOS in the naval rotary wing environment using current terminal technology. Future research will be able to validate the results as terminal technology continues to mature and MUOS reaches full operational capability.

II. LEGACY NETWORK CAPABILITY

A. HELICOPTER PLATFORMS

The United States Navy has operated various helicopter platforms over the years. Each helicopter was uniquely designed to serve a primary and various secondary roles within fleet operations. These operations included anti-submarine warfare (ASW), anti-surface warfare (ASuW), search and rescue (SAR) to include combat search and rescue (CSAR), as well as logistics and combat support. Inside each of these mission areas, different hardware requirements were needed and the aircraft outfitted accordingly.

The venerable CH-46 Sea Knight, and its vertical replenishment (VERTREP) mission associated with logistics transport did not need expensive networking capability. Logistics detachments usually operated in close proximity to the ships moving large amounts of cargo and personnel. As such, the CH-46 was only outfitted with a few radios operating in the UHF and VHF spectrum and some basic navigation equipment.

Other communities involved with integrated combat operations recognized the need for information and data other than voice. This would include track data, radar data, and acoustic data and later would incorporate full-motion video. The Helicopter Anti-Submarine Light (HSL) and later Helicopter Strike Maritime (HSM) squadrons would be equipped with aircraft that were integrated weapon systems with the host ships that they deployed from. The Light Airborne Multipurpose System (LAMPS) would be the first United States naval helicopter platforms to use integrated data link capability.

1. LAMPS Mk-I / SH-2 Seasprite

The first LAMPS helicopter weapon system was known as the LAMPS Mk-I. This system was placed on a Kaman UH-2 Seasprite. The Seasprite is a twin-engine helicopter with a max weight of 10,200 to 12,800 lbs depending on the variant over the years (see Table 1). The UH-2 entered service with the U.S. Navy in 1962 as a light utility helicopter and was used extensively in the Vietnam War as a search and rescue asset. In 1971, the Seasprite received the LAMPS Mk-I upgrade after being selected as the interim ASW platform and was re-designated the SH-2D. The weapon system was subsequently improved upon with the SH-2F (see Figure 1) that included upgraded engines and sensor suite (Frawley, 2002).

Figure 1. SH-2F Seasprite (photo credit PH2 Wiggens, 1983) Retrieved from http://www.DODmedia.osd.mil/Assets/1987/Navy/DN-SC-87–08838.jpeg

The LAMPS Mk-I system was used to extend the ASW capability of non-aviation ships. The system also had additional benefits of increasing the surface picture with a chin-mounted radar and eliminating elevation issues associated with radar coverage provided by surface ships. Over the horizon targeting was also a capability of the LAMPS Mk-1 system, assisting the surface ship in ASuW.

The data link capability on the SH-2D was provided by an AN/AKT-22 data set and was limited in throughput capacity. The AN/AKT-22 was used to link acoustic data between the aircraft and a LAMPS capable surface ship. With the ability to share data and use the greater processing power available on the shipboard systems, the SH-2D/F became a very capable ASW and ASuW platform.

Table 1. SH-2 Seasprite Characteristics (from Frawley, 2002)

	UH-2A	SH-2F
Length	52 ft 2 in (15.9 m)	52 ft 2 in (15.9 m)
Rotor Diameter	44 ft (13.41 m)	44 ft (13.41 m)
Disc Area	1520.53 sq ft (141.26 sq m)	1520.53 sq ft (141.26 sq m)
Empty Weight	6,100 lbs (2,767 kg)	7,040 lbs (3,193 kg)
Max Weight	10,200 lbs (4,627 kg)	12,800 lbs (5,805 kg)
Powerplant	1 x GE T58-GE-8B, 1525 shp (1,137 kW)	2 x GE T58-GE-8F, 1,350 shp (1,007 kW) each
Rotor System	4 bladed main rotor, 4 bladed tail rotor	4 bladed main rotor, 4 bladed tail rotor
Vne	150 kts (173 mph)	150 kts (173 mph)
Vmax	141 kts (162 mph)	143 kts (165 mph)
V cruise	120 kts (138 mph)	130 kts (150 mph)
Range	582 nm (670 mi)	366 nm (422 mi)
Service Ceiling	17,400 ft (5,305 m)	22,500 ft (6,860 m)

2. LAMPS Mk-III / SH-60B

The continuation of the LAMPS weapon system was achieved with the fielding of the LAMPS Mk-III system, which was hosted via the Sikorsky SH-60B helicopter (see Figure 2). The SH-60B was the successor to the SH-2F, with its first flight in December 1979 and initial operational capability in 1984 ("aerospaceweb.org," 2011). The LAMPS Mk-III system was designed for operations and integration aboard non-aviation capable ships steaming independently and in conjunction with a Carrier Strike Group (CSG). Currently, these ships are composed of the Ticonderoga class cruiser (CG), Arleigh Burke class destroyer (DDG), and the Oliver Hazard Perry class frigate (FFG). LAMPS Mk-III systems also operated off of the now decommissioned Spruance class destroyers (DD) into the 2000s.

Figure 2. SH-60B Seahawk (photo credit Joshua LeGrande, 2006). Retrieved from http://www.navy.mil/view_image.asp?id=30400

The SH-60B is also a twin-engine helicopter, with a max gross weight of 21,884 pounds (see Table 2), significantly larger than the Seasprite helicopter that it replaced. The larger size of the Seahawk limited the aircraft from operating off of older frigates and the SH-2G continued to serve in a reserve capacity until the fleet was finally retired in May 2001 ("airforce-technology.com," n.d.). With the larger size came an increase in capability for the two primary roles as an ASW and ASUW asset.

Significant upgrades were introduced with the Mk-III system over the early Mk-I weapon system. The sensor suite on the SH-60B (see Figure 3) included the APS-124 surface search radar, AN/UYS-1 spectrum analyzer, AN/ARR 75/84 Sonobuoy receivers, AN/ASQ-81 magnetic anomaly detection (MAD) set, AN/ALQ-142 electronic support measures (ESM) receiving set, and optional AN/AAS-44 forward looking infrared (FLIR) system. All of these sensors were connected to the SSQ-89 ship weapon system by the AN/ARQ-44 data link, also known as Hawklink.

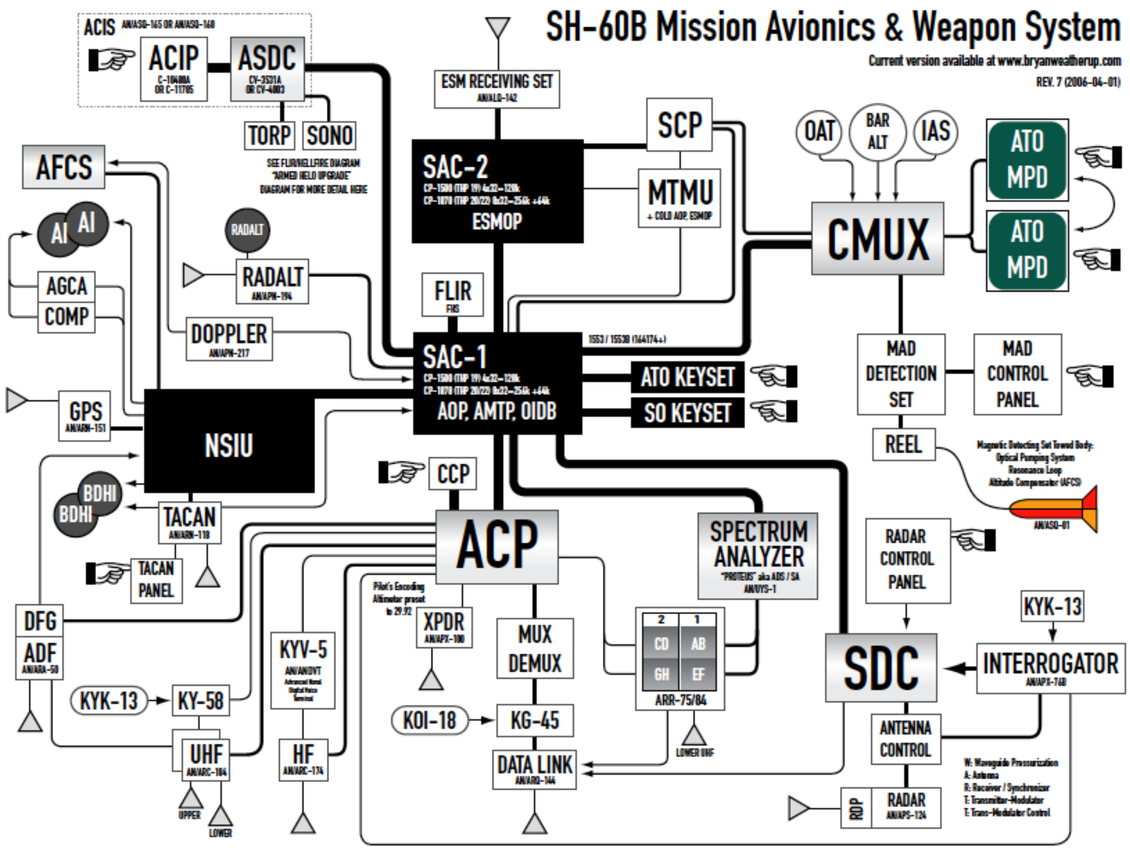

Figure 3. SH-60B Mission Avionics (from Weatherup, 2007)

In support of the ASW mission the LAMPS Mk-III would primarily use the UYS-1 spectrum analyzer in conjunction with various sonobuoys. These included directional and omni-directional, active and passive buoys such as LOFAR/DIFAR, DICASS, and VLAD buoys. The raw information from the buoys was received by the AN/ARR receivers to be processed by the UYS-1 onboard the aircraft or sent to the ship via Hawklink where larger and more capable systems were housed.

Along with sonobuoys, other non-acoustic sensors were also used to prosecute the ASW mission. Surfaced submarines could often be located using the APS-124 radar, which also has a mode for periscope detection. Submarines or surface ships while transmitting in the radio frequency (RF) spectrum could be intercepted, as the ALQ-142 ESM would be able to acquire a line of bearing and determine source equipment from the RF signature. A higher-level analysis of the RF signal is available via the ship's SLQ-32

ESM system, as raw data would be sent down the link to the ship. The MAD system could be employed against shallow undersea targets to gain a better understanding of the ASW picture. All of this information would be sent to the ship via Hawklink, to include track data, and incorporated into the ASW picture by the Anti-Submarine Tactical Air Controller (ASTAC) and subsequently support the common operational picture (COP) referenced by all vessels in the battle group.

The ASuW mission was prosecuted in a similar fashion as the ASW scenario. The LAMPS Mk-III aircrew using the radar, ESM, FLIR, and visual sightings would generate tracks. Once a track was generated the system would automatically send the information to the ship including location, course, and speed depending on the sensor used to acquire the track. The ability to share this information allowed targets to be prosecuted by the aircraft or the ship using over-the-horizon (OTH) targeting and engagement methods.

The Hawklink is the core of the LAMPS Mk-III weapon system and is used to maximize capability in conjunction with the resources provided by the ship. Onboard the ship all LAMPS Mk-III sensor data is processed and displayed by the AN/AQQ-89 ASW Combat System (ASWCS). The AN/AQQ-89 is used in both ASW and ASuW mission areas while processing data from the LAMPS Mk-III system. The shipboard systems are also able to transmit data to the helicopter via Hawklink to increase situational awareness and assist in the employment and prosecution of surface and sub-surface targets. The ability to share data between platforms is vital in effectively and efficiently carrying out the wide range of mission tasking.

Table 2. SH-60B Seahawk Characteristics (from Naval Air Systems Command [NAVAIR], 2004)

	SH-60B
Length	64 ft 10 in (19.75 m)
Rotor Diameter	53 ft 8 in (16.35 m)
Disc Area	2,262 ft^2 (210 m^2)
Empty Weight	13,648 lb (6,189 kg)
Max Weight	21,884 lb (9,924 kg)
Powerplant	2 × General Electric T700-GE-401C turboshaft, 1,890 shp (1,410 kW) take-off power each
Rotor System	4 bladed main rotor, 4 bladed tail rotor
Vne	180 kts (207 mph)
V cruise	120 kts (138 mph)
Range	450 nm (518 mi) internal
Service Ceiling	22,500 ft (6,860 m)
Armament	Up to three Mark 46 torpedos or Mk-54s, AGM-114 Hellfire missile, 4 Hellfire missiles AGM-119 Penguin missile (being phased out), M60 or, M240, or GAU-16/A machine gun

3. LAMPS MK-III / MH-60R

The LAMPS MK-III system was upgraded in the early 2000s with the introduction of the MH-60R (see Figure 4). The MH-60R shared many physical features with the SH-60B as seen in Table 3, with early production coming from retrofitted HSL Seahawk platforms. After the retrofit all squadrons receiving the MH-60R would be re-designated from HSL to HSM in accordance with the U.S. Navy helicopter master plan.

Figure 4. MH-60R Seahawk Retrieved from http://www.aviationnews.eu/31580/korea-mh-60r-seahawk-multi-mission-helicopters/

The sensor suite associated with the MH-60R continued to give aircrews radar, ESM, and sonobuoy capability. The biggest change to the ASW sensor suite was the addition of the Airborne Low Frequency Sonar (ALFS). The ALFS system is used in conjunction with the UYS-2 spectrum analyzer that has also been upgraded from the previous LAMPS Mk-III system. The introduction of the ALFS dipping sonar system is a significant increase in ASW capability over previous LAMPS aircraft.

Radar coverage is accomplished using the AN/APS 147 Inverse Synthetic Aperture Radar (ISAR), which gives the aircraft the ability to identify tracks based solely on radar data. The upgraded ESM suite, to include the AN/ALQ-142, enhances the MH-60R's ability to accurately display the surface RF picture and disseminate the data throughout the fleet.

Data communications on the MH-60R are handled by two separate link systems. The first system was previously discussed and consists of the AN/ARQ-44 Hawklink.

Hawklink is a full duplex SHF, C-Band line of sight data system that is able send voice, track data, and full-motion video at up to 10 Mbps to LAMPS capable ships via the SQR-4 antenna and SQQ-89 weapon system. In 2005, Harris Corp was awarded a contract to upgrade the legacy Hawklink to a common data link (CDL) standard ("Harris Corp.," 2005).

The new Hawklink will operate in the Ku spectrum with data rates up to 45 Mbps, more than double current Hawklink bandwidth capabilities. This new capability will be accomplished by upgrading existing shipboard hardware such as the SQR-4 antenna and replace the AN/ARQ-44 with the AN/ARQ-58 data link set in the helicopters. Final implementation of the Hawklink upgrade was awarded to L-3 Communications and is set to be complete by 2017 (Shephard News Team, 2012).

Link 16 has also been incorporated in the latest LAMPS Mk-III upgrade and in the MH-60S. With the addition of Link 16, Navy helicopters are now able to orient themselves via the COP, bringing situational awareness closer to other tactical officers onboard ships and C2 aircraft. Navy helicopters can push tracks into the COP as well as receive tracks, enabling the battle group commander more flexibility when deploying assets for both ASW and ASUW mission sets.

The Link 16 system is an ultra-high frequency (UHF), line of sight RF data link. Links between units in a BLOS environment must use an airborne or surface relay unit. Within a battle group the airborne relay is normally tasked to the E-2C/D Hawkeye, but this can create problems when the helicopter is operating independently or far away from battle group assets. BLOS limitations are significant when working single ship operations such as counter drug or even counter piracy operations where distributed assets are necessary.

Another limitation to the Link 16 architecture is the restricted throughput associated with the system's architecture. Link 16 coded messages are usually sent at a rate of 27, 54, or 108 kbps, with the current Multifunctional Information Distribution System–Low Volume Terminal (MIDS-LVT) maxing out at 115 kbps (Martin, 2013). Imagery can be sent over Link 16 as well as free form text messages allowing for more flexibility amongst aircrews. Currently Naval helicopters are unable to send full-motion video over the Link 16 system due to bandwidth capacity issues. The ability to send full-motion video to anyone on the Link 16 network would be a substantial increase in capability to an ISR asset.

The hardware associated with the Link 16 system includes a MIDS-LVT and antenna system. Training with the Link 16 system in CONUS is difficult due to the restrictions placed upon the DOD by the Federal Aviation Administration limiting the number of participants on the network. This limitation is imposed because of possible interference with domestic radio and navigational aids as the Link 16 operates in the same frequency band of 960–1215 MHz (Chairman of the Joint Chiefs of Staff Instruction [CJCSI], 2012).

Table 3. MH-60R Characteristics (from Naval Air Systems Command [NAVAIR], 2010)

	MH-60R
Length	64 ft 10 in (19.75 m)
Rotor Diameter	53 ft 8 in (16.35 m)
Disc Area	2,262 ft² (210 m²)
Empty Weight	14,430 lb (6,545 kg)
Max Weight	23,500 lb (10,659 kg)
Powerplant	2 × General Electric T700-GE-401C turboshaft, 1,890 shp (1,410 kW) take-off power each
Rotor System	4 bladed main rotor, 4 bladed tail rotor
Vne	180 kts (207 mph)
V cruise	120 kts (138 mph)
Range	450 nm (518 mi)
Service Ceiling	22,500 ft (6,860 m)
Armament	Up to three Mark 46 torpedos or Mk-54s, AGM-114 Hellfire missile, 4 Hellfire missiles M60 or, M240, or GAU-21 machine gun

4. MH-60S Nighthawk / HH-60H Seahawk

The MH-60S (see Figure 5) is a naval variant of the Army's UH-60 Blackhawk utility helicopter. The MH-60S was initially procured to replace the aging CH-46 Sea Knight helicopter and carry on the fleet logistics mission of the Helicopter Combat

Support (HC) community. Reaching operational capability in the early 2000’s, HC squadrons were renamed HSC while being realigned with HS squadrons. With the helicopter reorganization plan, the MH-60S would become the U.S. Navy’s logistics, CSAR, and ASuW helicopter based on air capable ships and USNS supply ships.

Figure 5. MH-60S Knighthawk (photo credit Esa Kaihlanen, 2014). retrieved from http://gmail.airliners.net/photo/USA---Navy/Sikorsky-MH-60S-Knighthawk/2572618/&sid=05fa0dacba2b5fcf500175a279c76a5d

Primarily designed as a logistics support helicopter, the MH-60S has little in the way of organic sensors. With the block II upgrade the Knighthawk did receive the AN/AAS-44C Multispectral Targeting System (MTS). The MTS has FLIR, day TV, low light TV, a Laser rangefinder/designator, and night vision device (NVD) compatible target marker. Subsequent upgrades to include the Armed Helicopter Kit, gave the MH-60S significant punch in the ASuW role, with the ability to carry up to 8 Hellfire air to ground missiles and 2 GAU-21, 50 caliber machine guns, one on each side (see Table 4).

The Knighthawk, lacking organic sensors, did not have a need to transmit large amounts of data into the overall surface picture. The addition of the MTS allowed the MH-60S to play a much larger role in supporting the ISR mission, but the system was unable to push imagery, mainly full-motion video to the ship. Multiple deployments have seen the use of the ROVER system to gain full-motion capability, although the transmit distance is relatively short and the data is not encrypted.

Link 16 is a very useful tool for MH-60S aircrews as it allows them to see the surface picture without having a surface search radar. Link 16 is also useful for keeping situational awareness of the air picture when operating in close proximity to other airborne units. Advances in Link 16 technology have allowed for more information to be passed, to include free form text and still photo imagery.

The legacy HH-60H that is still being used by the two Navy Reserve squadrons, HSC-84/85 does not have the ability to receive or transmit data outside of the retrofitted Blue Force Tracker system. Communication systems included in the legacy HH-60Hs are UHF/VHF/SATCOM via the AN/ARC-210 radio suite. HSC-84/85, which serve as the U.S. Navy's only dedicated Naval Special Warfare (NSW) support squadrons lack basic network centric capabilities such as Link 16. MUOS could play a major role in data communications if the Navy continues to operate these legacy platforms.

Table 4. MH-60S Knighthawk Characteristics (from Naval Air Systems Command [NAVAIR], 2012)

	MH-60S
Length	64 ft 8 in (19.75 m)
Rotor Diameter	53 ft 8 in (16.35 m)
Disc Area	2,262 ft^2 (210 m^2)
Empty Weight	13,648 lb (6,191 kg)
Max Weight	23,500 lb (10,659 kg)
Powerplant	2 × General Electric T700-GE-401C turboshaft, 1,890 shp (1,410 kW) take-off power each
Rotor System	4 bladed main rotor, 4 bladed tail rotor
Vne	180 kts (207 mph)
V cruise	120 kts (138 mph)
Range	245 nm (518 mi) internal
Service Ceiling	22,500 ft (6,860 m)
Armament	AGM-114 Hellfire missile, 8 Hellfire missiles M240, or GAU-21 machine gun

B. SATCOM SYSTEMS

Satellite communications (SATCOM) have been around for over half a century. Early in SATCOM development, terminal equipment was large and heavy and therefore relegated to large platforms such as ships and eventually large aircraft. While SATCOM technology continued to evolve, naval helicopters used high frequency (HF) communications to conduct limited BLOS operations. The current military satellite (MILSAT) communication system consists of various constellations to include Wideband Global SATCOM and Advanced EHF, with MUOS to come on line in the near future (see Figure 6). Focus in this chapter will be on the legacy systems that can be accessed by naval helicopters.

In 1981, the Navy introduced the Fleet Satellite Communications (FLTSAT) system to provide narrowband SATCOM to the operational community. By the late 1990s, the FLTSAT constellation was being replaced by the Ultra High Frequency Follow-On (UFO) system in order to upgrade capacity and maintain SATCOM capabilities to the fleet (Pike, 1997)

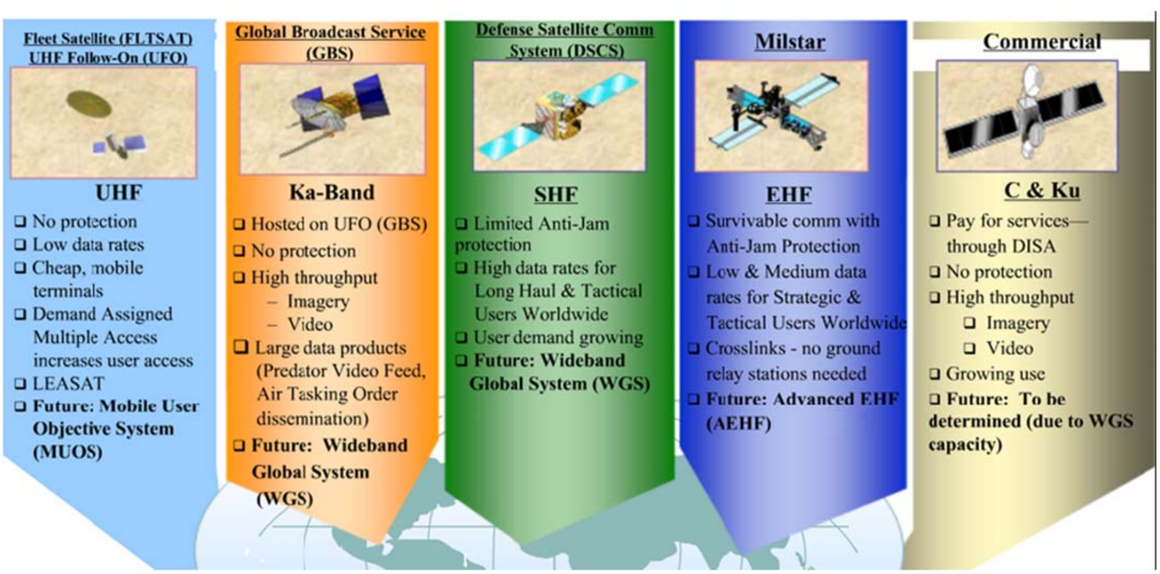

Figure 6. Current and Future MILSAT systems (from See, 2008)

1. FLTSAT

The FLTSAT communication system was a UHF-based satellite communication system developed and operated by the United States Navy. The constellation consisted of 8 satellites even though only 6 would reach operational status. The first satellite was launched in 1978 with the first four on orbit by the end of 1980. The constellation went operational in 1981 with a design life of 5 years, while satellites 7 and 8 continue to provide UHF communications today (Program Executive Officer Space Systems [PEO Space], n.d.).

Each satellite consisted of a UHF antenna and 12 transponders operating in the 240–400 MHz range. The last two satellites also contained EHF payloads that allowed for greater capacity. Communication paths were separated into 23 distinct channels with the United States Navy using 10 and the United States Air Force using 12 for their satellite communications networks. The additional channel was used for United States National Command Authorities (Pike, 1997).

2. UFO

The UFO satellite constellation was established by the U.S. Navy to provide narrowband communication for military operations worldwide. Eleven total satellites were constructed with the last launch in 2003 (Program Executive Officer Space Systems [PMW-146], n.d.). The current UFO geographic footprint is shown in Figure 7. Each satellite consists of multiple transponders that act as a bent pipe for communications and operate in both the UHF and VHF spectrums to provide direct point-to-point links. Uplink is accomplished by accessing channels between 292 MHz to 317 MHz, while the downlink frequency band is located between 243 and 270 MHz (Huckell & Parsons, 1999). Each satellite is able to support 39 separate communication channels broken down into 17, 25 kHz channels and 21, 5 kHz channels along with one fleet broadcast channel for a total of 555 kHz of total bandwidth capacity (Program Executive Officer for Space, Communications and Sensors [PMW-146], 1999). Multiple satellites are able to co-locate in order to increase capacity as dictated by demand. The UFO constellation has been upgraded to carry SHF and EHF payloads in the later satellites. As Navy helicopters are unable to access this communication link, it will not be discussed in this thesis.

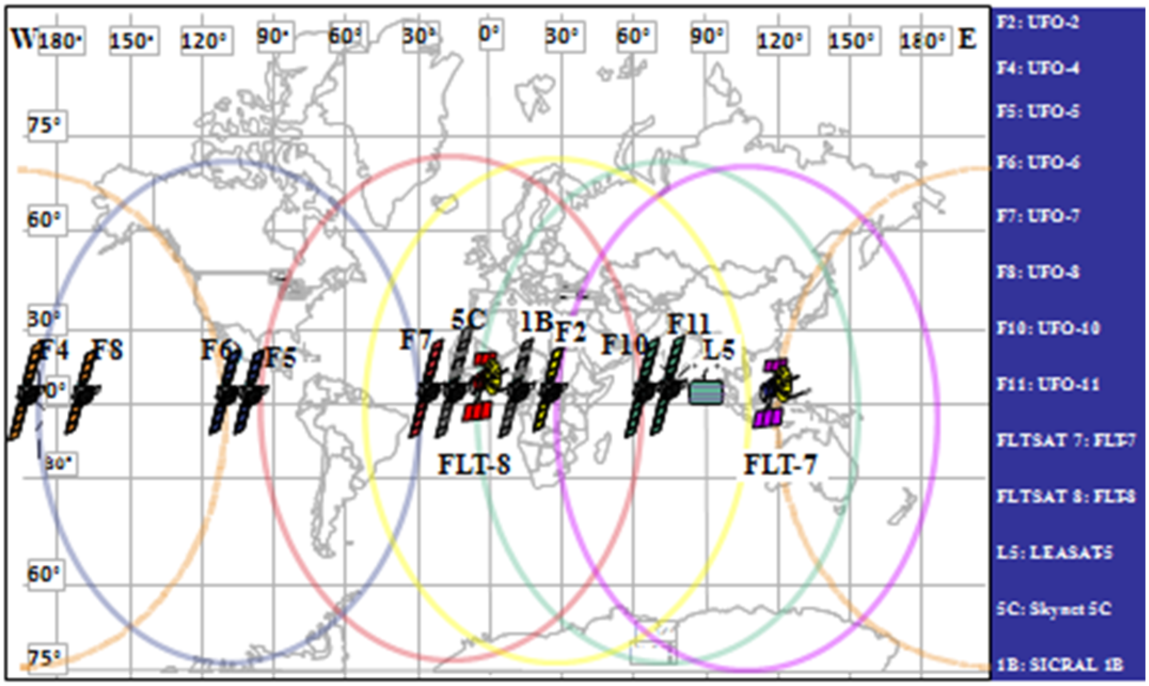

Figure 7. Current UHF SATCOM (from King, 2010)

As mentioned before, the UFO satellites have 39 channels and 555 kHz of bandwidth for use at any given time. During the early stages of satellite communication and even today, individual units would occupy entire channels independent of bandwidth allocation or need. This type of communication is better known as single access mode and the amount of users on the network is limited to the number of uplink and downlink channels supported.

To make better use of the finite resources associated with these satellites, a protocol called Demand Assigned Multiple Access (DAMA) was created to allow multiple users on different networks to use the same channel. The DAMA standards used by the military are time division multiple access (TDMA) schemes in order to more efficiently use the allocated bandwidth (Huckell, Tirpak, & Chandler, 1999). A TDMA schema allows multiple users access to a channel based on dividing the channel by time.

Users would communicate in bursts within a given time slot on a select channel. While operating in their time slot the end user would have dedicated access to the channel and all the services associated. Once the transmission was complete the resource would then be free to be assigned to another user on a different network. A TDMA network is controlled by a network control station, which sends specific messages at precise times or intervals also called frames. Each frame consists of multiple slots that are either used by the network control station to administer the network or allocated to end users for data transmission to each other (Huckell et al., 1999).

Within the DAMA/TDMA framework, two different waveforms were developed to conform to the military standard (MIL-STD). The two waveforms are employed on channels of two separate bandwidths, 5 kHz and 25 kHz. The standards describing these waveforms are found in the MIL-STD-188–182 and 183. The 5 kHz protocol has the capacity to support multiple users with voice and data rates to 2.4 kbps. Each 25 kHz channel can support up to 5 users with 2.4 kbps secure voice and data or up to 16 kbps of data throughput over the entire channel. An upgrade to the DAMA MIL-STD can increase the number of supported users to 12 on a 25 kHz channel utilizing an integrated waveform (Huckell & Parsons, 1999).

The ability to use the current SATCOM capability is degraded by the latency in the transmissions. This has to due with both time to travel of the signal and the architecture for accessing the network. Figure 8 depicts the sequence required for data transmission over the current UHF satellite system. Four separate ground stations located around the world handle access and control of the network. These Naval Computer and Telecommunications Area Master Stations (NCTAMS) are geographically located inside of two satellite coverage areas, in order to provide backup control of the networks in case an adjacent ground facility becomes non-operational. The locations of these NCTAMS ground facilities are listed in Table 5.

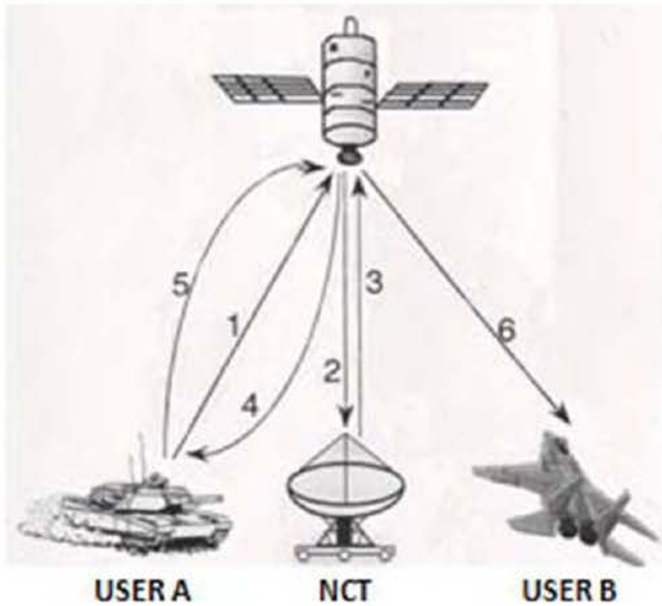

Figure 8. SATCOM DAMA Transmission Sequence (from Feldman, 1996)

The UHF SATCOM DAMA protocol has been the standard for satellite communications for naval helicopters, though single access mode is also available. With limited capacity on the network, training and operational use is usually limited to operations with naval special warfare units that are allocated time on the network. Currently all United States Navy helicopters have access to the UHF SATCOM network via the AN/ARC-210 multifunction radio.

Table 5. DAMA Primary Channel Controllers (from Matassa, 2011)

DAMA Primary Channel Controller	NCTAMS Location	Satellite Footprint
NCTAMS LANT	Norfolk, VA	Continental U.S.
NCTAMS EURCENT	Naples, Italy	Atlantic Ocean
NCTAMS PAC	Wahiawa, HI	Pacific Ocean
NCTS Guam	Finegayan, Guam	Indian Ocean

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III. MOBILE USER OBJECTIVE SYSTEM (MUOS)

A. BACKGROUND

Operations in austere and challenging geographical environments that limit line of sight communications (LOS) are dependent on the use of beyond line of sight (BLOS) technology. Legacy tactical SATCOM networks have been the primary means of BLOS communication for the past decade and are already past their expected end of life. MUOS is the next generation in tactical satellite-based networks to be fully operational by FY2017. The operational date has pushed to the right due to various reasons including ground station issues in Italy, terminal availability and waveform development problems. MUOS will provide compatibility with legacy SATCOM networks but will increase the throughput sixteen fold (Lockheed Martin Space Systems Company, 2014). Along with legacy voice capability MUOS will provide the end user an IP-based network option to connect to the Global Information Grid (GIG) via the Defense Information Service Agency's network. This will allow the operator on the ground or in the air access to NIPR, SIPR and JWICS services at a touch of a button.

B. HARDWARE AND ARCHITECTURE

This section will explore how MUOS is able to transmit data throughout the world. The ability to conduct BLOS communications requires the combination of many engineering disciplines to include space systems and RF spectrum expertise.

1. System Description

The MUOS system is comprised of both hardware and software components. The hardware discussion will be restricted to the satellites, radio access facilities (RAFs), and end user terminals. The overall architecture will address the waveform and communication pathway for all data transmissions.

a. Hardware

The MUOS satellite constellation will consist of 5 satellites in geosynchronous orbit (see Figure 9) with 4 satellites providing worldwide coverage and one on orbit spare. In addition to providing spectrally adaptive–wideband code division multiple access (SA-WCDMA) technology, each satellite will carry a legacy UHF SATCOM payload using frequency division multiple access (FDMA) and dedicated narrow band channels (Oetting & Jen, 2011). This will allow the MUOS constellation backwards compatibility with existing SATCOM terminals. There are currently three satellites in orbit with the following two to be deployed within the next few years.

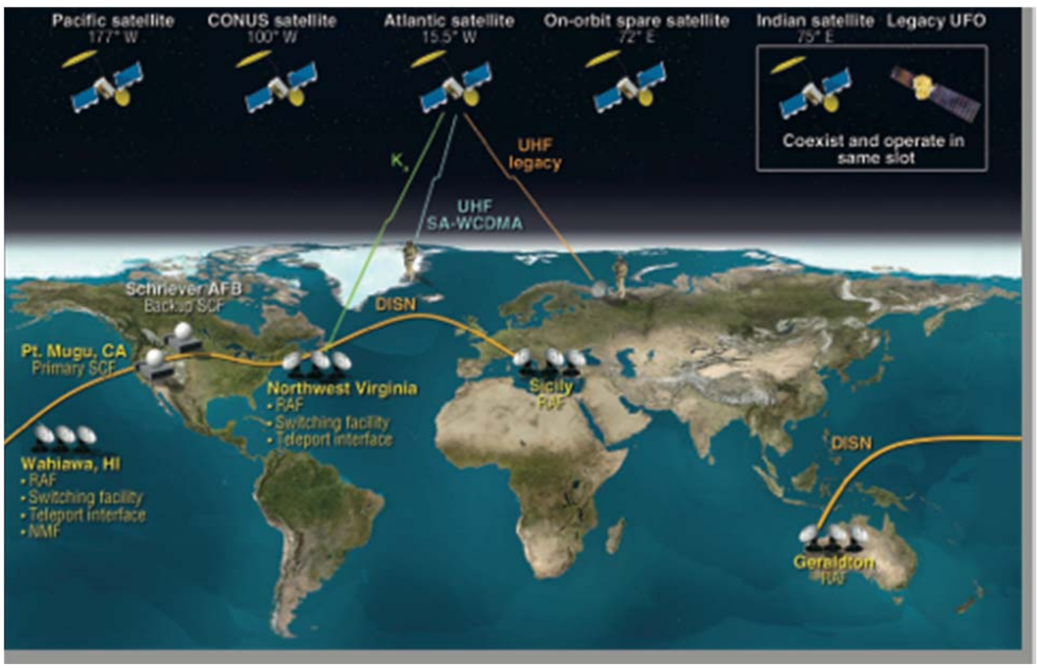

Figure 9. MUOS Concept (from Oetting & Jen, 2011)

The MUOS system also is composed of 4 RAF ground stations (Figure 10) positioned around the globe. They are located in Hawaii, Northwest Virginia, Sicily and Australia in order to maintain connectivity with at least two satellites at all times. At the same time, the satellites will maintain contact with at least two RAFs to insure data flow if one RAF would become inoperative. The RAFs are hardwired via a fiber optic backbone to each other and into Defense Information Switching Agency's (DISA) network and subsequently the GIG (Lockheed Martin Space Systems Company, 2010).

Figure 10. Radio Access Facility (photo credit Jacques, 2011) retrieved from http://www.gdc4s.com/news/image-gallery/mobile-user-objective-system-(muos).html

Access to the GIG from remote locations is the single greatest benefit of the system. Users will now have access to all areas of the NIPRNET, SIPRNET, and JWICS networks. Collaboration and integration issues in the joint environment will be significantly decreased with the use of the TCP/IP technology. Current operations allow for very little collaboration outside of voice communications. Voice communications have become standardized over the years, but at times are still ambiguous when used in a joint environment. The use of chat-based applications also allow for the recording of communication transmissions that can later be recalled for debriefing or other uses.

Another hardware aspect of the MUOS system is the end-user terminal. Currently, there are only two terminals fielded that will accept the MUOS waveform. These terminals are the AN/PRC-117G fielded by the Marine Corps and the AN/PRC-155 radio that is being procured by the U.S. Army. Rockwell Collins just completed in flight test of an upgraded ARC-210 (Figure 11) airborne radio that is widely distributed on aviation platforms. A recent demonstration flight by the United States Air Force exercised both the PRC-155 and the AN/ARC-210. Testing was successful as operators were able to conduct quality voice communications from over the Pacific Ocean to Scott Air Force Base as well as data transmissions of up to 5 MB (Gudaitis & Werner, 2014). Connection was lost at an angle of bank over 30 degrees but this occurs for legacy SATCOM systems as well.

Terminal development has lagged behind other areas of the system in order to capitalize on a mature satellite constellation and a standardized waveform. PMA-209 Air Combat Electronics, has recently started funding Rockwell Collins in order to field a MUOS capable AN/ARC-210 radio to the fleet with certification scheduled for 2017 (Navy Communications Satellite Program Office [PMW-146], 2014).

A possible benefit to terminal development is the user interface. Most of the terminals use either a tablet interface or laptop computer for portability. The next generation of warfighter is accustomed to these form factors and this may make training and operation of the systems easier in the future. One such user interface is the TacView by Esterline CMC Electronics as discussed later in the report (see Table 10). This is a small form factor tablet that can easily be accessed by aircrews and uses a familiar graphical user interface.

Figure 11. Rockwell Collins AN/ARC-210 (from Rockwell Collins, n.d.)

b. Architecture

Waveform:

The MUOS waveform uses a SA-WCDMA protocol, similar to what is in use by cell companies but modified to DOD specifications. Using this technology MUOS is able to increase the data load 16 times more than existing SATCOM constellations. MUOS users will be able to access the DISA's terrestrial voice and Internet Protocol (IP) networks at rates from 2.4 kbps up to 384 kbps (Lockheed Martin Space Systems Company, 2014).

UHF uplink and downlink bandwidths are constrained to a 20 MHz spectrum each. Uplink transmissions are carried at 300 to 320 MHz and downlink at 360 to 380 MHz. Each 20 MHz band will be broken up into four 5 MHz WCDMA channels. Theoretically 500 users will be able to use each channel by applying code-spreading technology. Reuse of the four channels allows for each satellite to transmit up to 64 channels with 32 channels split between the two RAFs in view of the satellite (Oetting & Jen, 2011).

Routing:

The entire MUOS network is made up of four different types of nodes. They consist of the end terminal, satellite, RAF, and switches. The routing protocol used is Open Shortest Path First (OSPF), which is a standard protocol used in TCP/IP applications (Lockheed Martin Space Systems Company, 2010). Once connected to the network the end user will be able to use address based routing also commonly used to access the Internet.

The MUOS network will be controlled via an automated network management system to assist in planning, allocating, and prioritizing accesses to resources. The network management system must be able to rapidly and dynamically configure and reconfigure network resources within 15 minutes and for selected high priority networks within 5 minutes (DOD CPD, 2008).

Each MUOS satellite utilizes a multibeam antenna that transmits 16 beams to cover the entire footprint of the satellite (see Figure 12). Each beam is like a cell tower that covers approximately 600 square miles of earth (Buck & Russ, 2007). Using a multi beam antenna allows for a gain increase compared to legacy platforms and reduces power requirements for end user terminals.

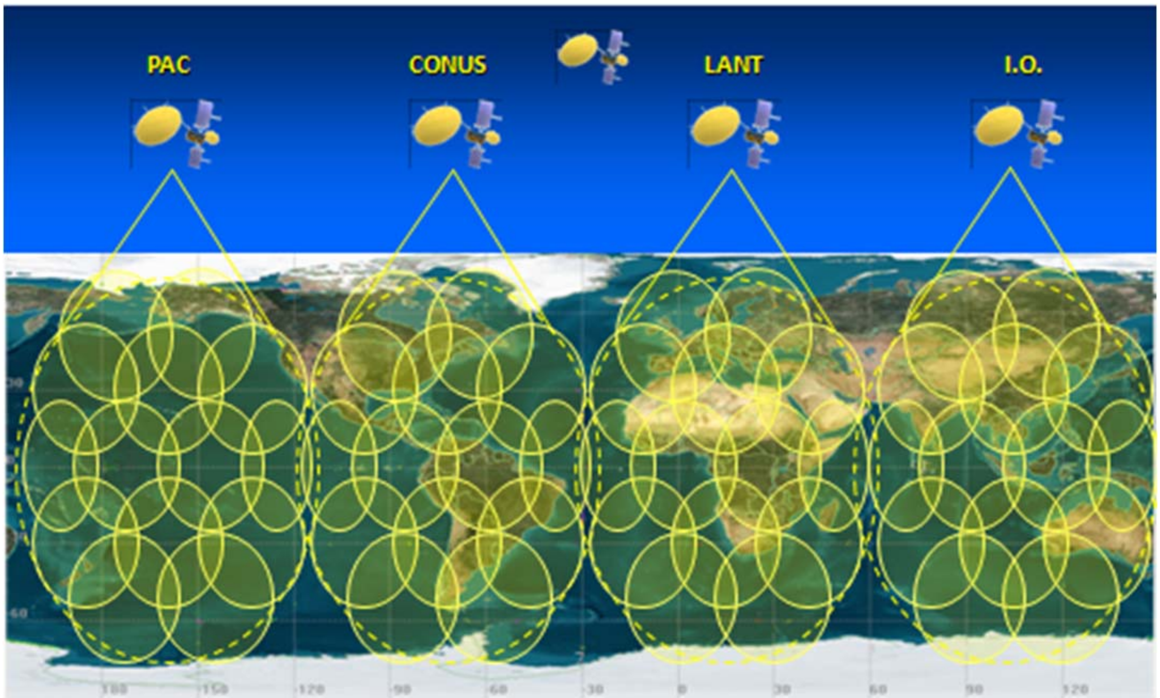

Figure 12. MUOS Spot Beam Coverage (from Buck & Russ, 2007)

The communication pathway from end-user to end-user is depicted in Figure 13. Unlike the current UFO satellite system that acts as a bent pipe between users when using dedicated access mode, MUOS always relays the data to the RAF, independent of type of data transmitted. The MUOS architecture is also the same independent of end user's geographic location and requires at least four terrestrial to satellite propagation delays.

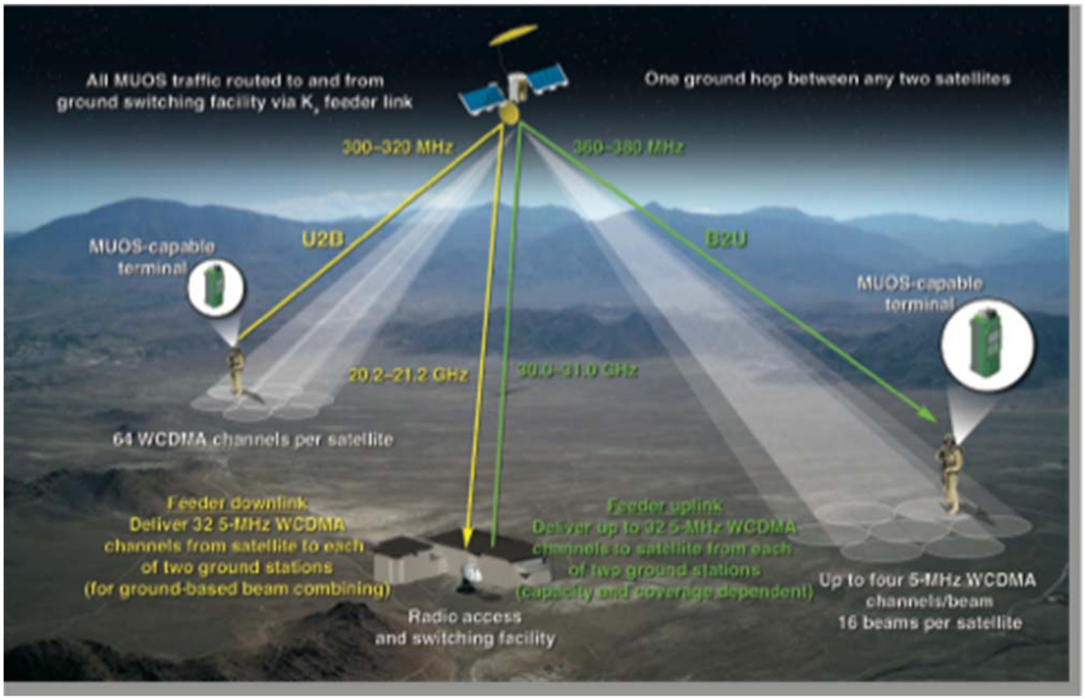

Figure 13. MUOS Pathway (from Oetting & Jen, 2011)

If the end users are within the footprint of different satellites, the RAF sends the data through a switching facility that routes it to the appropriate RAF for uplink to the satellite as seen in Figure 14. Routing for users under a single satellite footprint is similar but does not require the additional switching to another RAF. Placing the switching stations on the ground reduces the amount of processing required by the satellite (Lockheed Martin Space Systems Company, 2010).

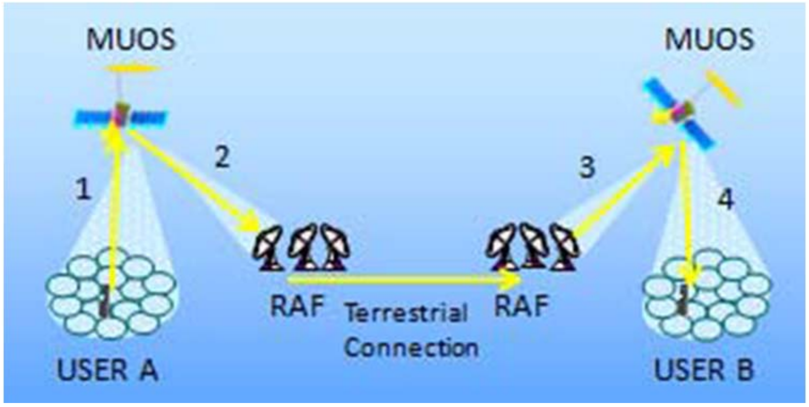

Figure 14. Data Flow via 2 Satellites (from King, 2010)

2. Status

Current:

As of March 2015 there are currently 3 satellites in orbit with the remaining 2 in various states of production. Final assembly on the fifth satellite was completed in January 2014 and it has entered the testing phase. Full operational capability is slated by FY2016 as stated in the MUOS Capabilities Production Development document (PMW 146, 2008). The AN/PRC-117G is the only radio currently fielded to accept the MUOS waveform. The U.S. Army is currently procuring the AN/PRC-155 that will have the MUOS waveform natively built in. All four RAFs are operational with the Sicily station delayed briefly due to local protests of increased radiation hazards.

Future:

Full operational capability of the MUOS system is to be achieved by FY2017 (Lockheed Martin Space Systems Company, 2014). This is almost 2 years behind initial estimations. Increased development of user terminals will be required to take advantage of the unique network capabilities. Airborne terminals are entering in-flight testing and will be available in the near future.

More studies need to be conducted concerning interference with the legacy SATCOM payload carried by the MUOS constellation. The frequency band of the UFO (292–318 MHz) constellation overlaps the MUOS uplink frequency range (300–320 MHz). Interference level analysis was performed and entered in to the required specifications but early modeling was far from complete (Oetting & Jen, 2011).

Once more end user terminals are available, field level experiments can be conducted to validate theoretical concepts of operations. MUOS has applications involving all aspects of warfare to include air-ground communications in support of regular troops, SOF operations, and Humanitarian Assistance and Disaster Relief (HADR).

C. OPERATIONAL CAPABILITY

When assessing MUOS capability, we need to compare it against the legacy network capacity. A single UFO satellite can carry 106 different voice nets operating at 2.4 kbps simultaneously and you can double that with another co-located UFO satellite for a total of 212 voice nets in a geographic area. Added together, a UFO constellation can provide up to 508.8 kbps of total data throughput. A single MUOS satellite will be able to support up to 4,083 individual nets and an additional 106 from the legacy payload, for a combined total of 4,189 simultaneous transmissions at 2.4 kbps. Total capacity from a single MUOS satellite is 10.05 Mbps, an increase of over 16 times current UFO capability as shown by Figure 15 (King, 2010).

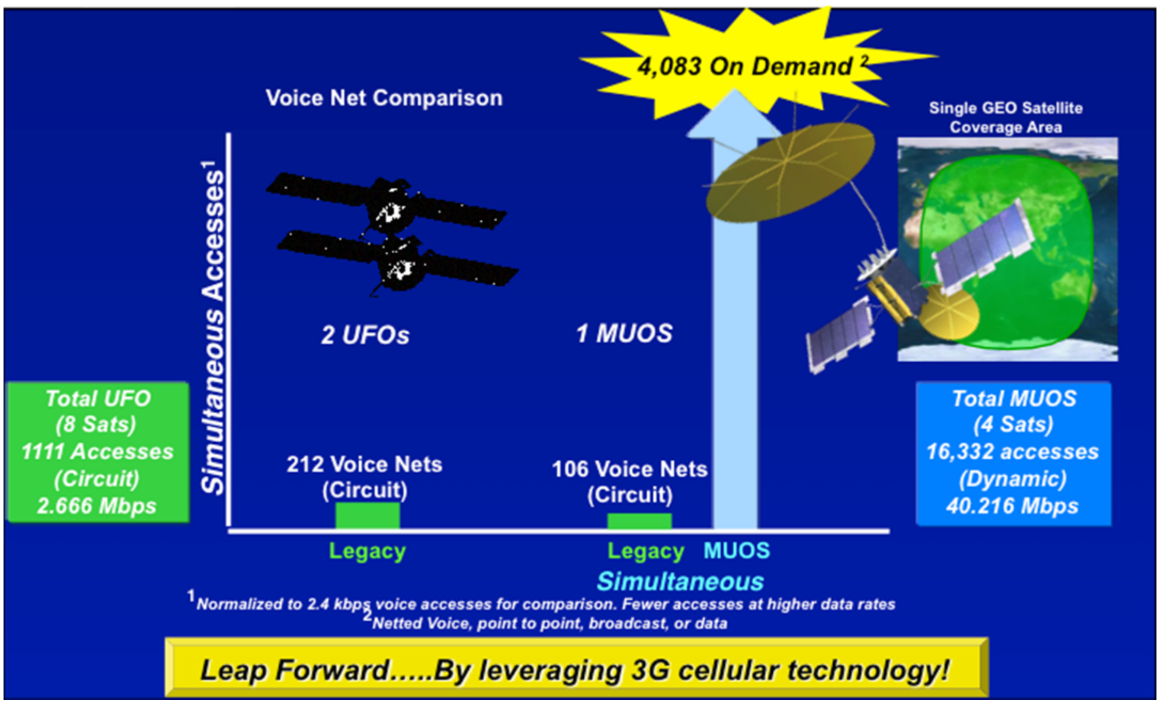

Figure 15. MUOS vs Legacy Capacity (from King, 2010)

The significant increase in performance is due to the utilization of the WCDMA technology. Each WCDMA carrier has a maximum of 512 channelization codes. These codes are assigned on a need basis for varying data rates as seen in Table 6. An increase in data throughput need results in the issue of more codes to a single user, therefore diminishing the throughput of other users or reducing the number of users able to access the carrier (Lockheed Martin Space Systems Company, 2010).

Table 6. Number of Codes Required Given a Data Rate (from Lockheed Martin, 2010)

	Service			
	64 Kbps	32 Kbps	9.6 Kbps	2.4 Kbps
Number of Codes Required	16	8	2	1

Operationally, different assets will be allowed dedicated bandwidth based on the type of platform and operating environment. A representation of platforms and their associated data rates is summarized in Table 7. Helicopters are assigned a relatively low maximum data rate, which may impact the types and quality of data that can be transmitted. Even platforms allocated more bandwidth are still restricted compared to current line of sight communications networks.

Concepts of operations (CONOPS) will need to address the limitations imposed by the system itself and also the network management policy. CONOPS associated with ISR assets will be the most impacted by the network management policy regarding the sharing of full motion video and large imagery files. Additionally, access to the GIG and Internet will be restricted to low bandwidth or mobile designed websites that cater to platforms with restricted data flow.

Table 7. Terminal Data Rates (from King, 2010)

Terminal Configuration	User/Platform	Data Rate (kbps) By Environment: Optimum	Data Rate (kbps) By Environment: Highly Stressed	Terminal Speed (Maximum) (mph)
Aircraft	Large Aircraft	64	32	900+
Aircraft	Fighter/Attack	16	16	900+
Aircraft	Helicopter	16	16	220
Aircraft	UAV	64	64	460
Aircraft	Missile	32	32	667
Handheld	Soldier	32	9.6	6
Handheld	Vehicle	64	32	65
Manpack	Soldier	64	64	0
Manpack	Vehicle	64	64	0
Manpack	Vehicle	64	32	65
Manpack	Advanced Amphibious Assault Vehicle (AAAV)	64	32	45
Sensor	Remote Sensor	2.4	2.4	0
Ship	Large/Small Deck	64	64	30+
Submarine	SSN/SSBN	64	32	25+
Boat	Pursuit Boat	2.4	2.4	60+

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IV. MUOS APPLICATION

A. INTRODUCTION

The application of the Mobile User Objective System (MUOS) in the naval helicopter community is just being explored. Helicopters have had SATCOM voice capability for some time, but network capacity issues, often limit actual use. MUOS will increase access to satellite communications networks previously only used during combat operations or in unique training environments with small ground units.

Beyond line of sight (BLOS) data capability is an intriguing addition to the naval helicopter community. While Hawklink and Link 16 provide line of sight data communication paths, they are limited in the type of information that may be passed based on the protocols used. MUOS will allow the end user to access the Global Information Grid (GIG) and take advantage of existing TCP/IP protocols that are standard across the Internet.

While MUOS provides a substantial increase in overall satellite network capacity, there are still limits based on the waveform and architecture of the network. The throughput is reduced even further by the introduction of policies to administer the network. PMW-146 envisions group communications, point-to-point, or point-to-network communications to be bounded at the terminal from 2.4 kbps up to 64 kbps (King, 2010). With these restrictions in place, applications can be simulated to assess their viability to the end user.

This section will analyze both voice and data communications as they relate to the end user and will break down the data communications into 4 separate elements. These elements will include JREAP/Link-16, web applications, text/chat and e-mail functions, and imagery to include both still and full-motion video.

To simulate the bandwidth restrictions placed on the network, a software program called NetBalancer will be used to artificially restrict data throughput to the various applications. NetBalancer is a network traffic control and monitoring tool that will enable a basic simulation of the MUOS network as seen by the end user. A description on how to employ NetBalancer with screen shots is provided in Appendix A.

B. VOICE

Modern BLOS communications rely heavily on various satellite constellations. For years, the tactical operator either used the UFO system for narrowband communications or contracted with civilian companies for access to their satellite networks. In almost all cases, each satellite network acted like a bent pipe relaying the voice data directly from user to user. Each terminal must be connected to the satellite network when using the MILSAT constellations.

With the successful introduction of voice over Internet protocol (VOIP), terrestrial users were now able to use Internet connected networks to place voice calls anywhere in the world to any phone to include other computer applications. This same technology is used by MUOS when transmitting voice communications. By leveraging this technology the end user is able to not only call other MUOS terminals but also access the defense switching network (DSN) lines and commercial phones (Lockheed Martin Space Systems Company, 2010).

The ability to obtain voice communications with standard DSN or commercial phone contacts anywhere in the world allows the end user access to a wealth of information that was previously unavailable. If an aircrew has a mechanical issue in a remote location, MUOS would allow for them to contact technical representatives and possibly solve the issue within minutes. MUOS would also allow aircrews to communicate with subject matter experts regarding real time tactical observations.

Since voice communications require little relative throughput capacity, the MUOS network will be able to provide adequate service to the end user even given existing platform restrictions. MUOS is capable of providing point to point voice communications at either 2.4 kbps or voice recognition at 9.6 kbps and point to network IP communications at 9.6 kbps up to 64 kbps (King, 2010). These figures come in well below the notional restriction of 16 kbps, as seen in Table 7.

VOIP communications rely on a number of different codecs (coder / decoder) in order to translate the analog audio signal into a digital data able to be streamed over the Internet. Tables 8 and 9 show a sample of the various VOIP codecs in use today and required bandwidth. Using NetBalancer and SKYPE, a popular VOIP application that utilizes G.729 and a few proprietary codecs. Three simulations were completed and call quality was not acceptable. This was somewhat anticipated as SKYPE lists the minimum required bandwidth for an audio call at 30 kbps. Other applications may be used that require a lower bandwidth for naval helicopter operations.

Table 8. Codec Information (from CISCO, 2006)

Codec Information			
Codec & Bit Rate (Kbps)	Codec Sample Size (Bytes)	Codec Sample Interval (ms)	Mean Opinion Score (MOS)
G.711 (64 Kbps)	80 Bytes	10 ms	4.1
G.729 (8 Kbps)	10 Bytes	10 ms	3.92
G.723.1 (6.3 Kbps)	24 Bytes	30 ms	3.9
G.723.1 (5.3 Kbps)	20 Bytes	30 ms	3.8
G.726 (32 Kbps)	20 Bytes	5 ms	3.85
G.726 (24 Kbps)	15 Bytes	5 ms	
G.728 (16 Kbps)	10 Bytes	5 ms	3.61
G722_64k(64 Kbps)	80 Bytes	10 ms	4.13
ilbc_mode_20(15.2Kbps)	38 Bytes	20 ms	NA
ilbc_mode_30(13.33Kbps)	50 Bytes	30 ms	NA

Table 9. Codec Bandwidth Calculations (from CISCO, 2006)

Bandwidth Calculations						
Codec & Bit Rate (Kbps)	Voice Payload Size (Bytes)	Voice Payload Size (ms)	Packets Per Second (PPS)	Bandwidth MP or FRF.12 (Kbps)	Bandwidth w/cRTP MP or FRF.12 (Kbps)	Bandwidth Ethernet (Kbps)
G.711 (64 Kbps)	160 Bytes	20 ms	50	82.8 Kbps	67.6 Kbps	87.2 Kbps
G.729 (8 Kbps)	20 Bytes	20 ms	50	26.8 Kbps	11.6 Kbps	31.2 Kbps
G.723.1 (6.3 Kbps)	24 Bytes	30 ms	33.3	18.9 Kbps	8.8 Kbps	21.9 Kbps
G.723.1 (5.3 Kbps)	20 Bytes	30 ms	33.3	17.9 Kbps	7.7 Kbps	20.8 Kbps
G.726 (32 Kbps)	80 Bytes	20 ms	50	50.8 Kbps	35.6 Kbps	55.2 Kbps
G.726 (24 Kbps)	60 Bytes	20 ms	50	42.8 Kbps	27.6 Kbps	47.2 Kbps
G.728 (16 Kbps)	60 Bytes	30 ms	33.3	28.5 Kbps	18.4 Kbps	31.5 Kbps
G722 64k(64 Kbps)	160 Bytes	20 ms	50	82.8 Kbps	67.6Kbps	87.2 Kbps
ilbc_mode_20(15.2Kbps)	38 Bytes	20 ms	50	34.0Kbps	18.8 Kbps	38.4Kbps
ilbc_mode_30(13.33Kbps)	50 Bytes	30 ms	33.3	25.867 Kbps	15.73Kbps	28.8 Kbps

C. DATA

BLOS data transmission is not a current capability afforded the naval helicopter community. The addition of this capability will require extensive testing and overhaul of various tactics, techniques, and procedures (TTPs). Discussions with numerous pilots in both the HSM and HSC communities narrowed a list of possible data applications relevant to helicopter operations. Link 16 Capability via JREAP was mentioned by many of the pilots during informal discussions and was of great interest to HSC Weapon School Pacific. All of the helicopter pilots expressed the need for imagery, and the ability to both receive and push imagery into the network. Web applications were also discussed, as MUOS provides access to the GIG and actionable information it contains. Finally, the Navy and Department of Defense is dependent on electronic mail and other forms of communication such as Chat and Text that may be useful to aircrews operating in a BLOS environment.

1. Link 16 via JREAP

Link 16 is crucial to both naval and joint operations. The situational awareness provided to aircrews increases the overall effectiveness of the platform in a network centric battle space. For years HSL aircrews relied upon the ASTAC to provide accurate and timely updates to the tactical picture via Hawklink. HS and HC platforms were only able to obtain the operational picture via UHF/VHF voice communication and therefore were limited in their ability to effectively receive or relay information. Both the HSM and HSC communities currently operate in the Link 16 environment by incorporating a MIDS-LVT terminal on the MH-60R and MH-60S, respectively. This allows for all aircrews within the link to share the same common operational picture.

What happens if the helicopter is operating independently or operating in a low altitude environment that blocks the traditional line of sight path of the Link 16 network? Joint range extension application protocol (JREAP) increases the availability of Link 16 messages to be sent over a variety of mediums to include satellites and Internet protocol (IP)-based networks. Figure 16 depicts the paths by which Link 16 data from various JTIDS zones can be shared throughout the battle space.

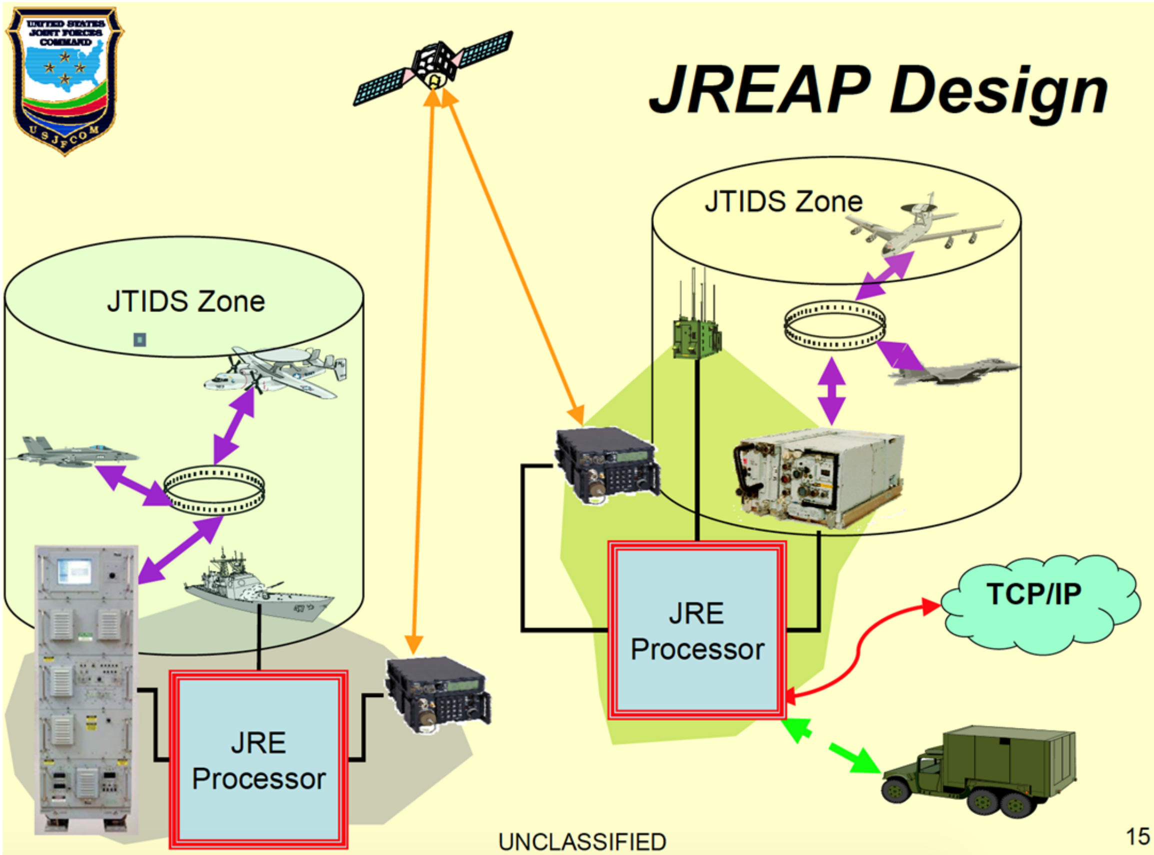

Figure 16. JREAP Design (from Bass, n.d.)

The JREAP standard was initially focused on the ability to access J-coded messages but was also written to support additional tactical data links (TDL) and was adopted as a MIL-STD in 2002 (3S Data Links, 2008). The naval helicopter application of JREAP could provide multiple advantages to include extending the range of TDLs, providing backup link capability, and offering a cost effective way to connect non-TDL platforms. HSCWSP expressed interest in extending the range of Link 16 when operating overland or a significant distance from the Carrier Strike Group (CSG) or Amphibious Ready Group (ARG). Mentioned previously, HSC-84/85 are currently operating legacy HH-60H aircraft which do not have any link capability, but could easily incorporate a MUOS capable AN/ARC-210 radio and a JREAP terminal as seen in Table 8. The Esterline CMC Electronics JRE enabled TacView has recently been selected for use in the Coast Guard's MH-65 helicopter. Used in conjunction with the L-3 Communications JRE data link gateway, this capability will enable the aircrews to have much greater situational awareness. Mike Lawson, vice president, Advanced Technologies Department, L-3 Communications, stated: “The JRE-Enabled TacView ... or JET as we like to call it ... is a powerful system that provides U.S. Coast Guard helicopter crews with an unprecedented capability to reduce their workload, enhance their mission effectiveness and increase aircrew safety” (“Aero News Network,” 2012).

Table 10. CMC TacView JRE Terminal (from Joint Range Extension [JRE], n.d.)

	Capabilities: - Edge to edge moving map, switch between track or north up - Cockpit friendly single bezel push / touch screen touch for most desired - Functions /crew actions (assignments, text, imagery, map control) - Tactical tools : range & bearing, bulls eye, instant geo-location - Imagery (J16.0) functionality (also enables file transfer), Text (J28.2) - Mission Assignments (J12 0) for W LCO/CANTCO, status , BDA - Digital CAS and Electronic Warfare (EW J14.0, J14.2) Support - JREAP-A, B & C (including Multicast) IAW M L-STD 3011A - Host & control SADL 11xy & SADL 11z radios - Host Link-16 Terminals (LVT-1 IP/1553, LVT-2 P, STT P, MIDS on Ship) - Display automated Information System (Maritime) tracks - Non C2 License for tactical ops, C2 License for Digital Tasking Authority - JRE VMF implementation IAW MIL-STD-6017 and MIL-STD-6020	Features: - NVIS Compatibility to MIL-STD-3009 - Sunlight readability to MIL-L-85762A - Sliding QWERTY Keyboard - Enhanced bezel buttons for flight glove operation - Security Features: PXE remote server booting, removable drives for declassification - Electronic Flight Book –paperless cockpit options - D0-160E/ED-14 Qualified - I/O Options: MIL-STD 1553B, USB 2.0, AR NC 429, - Base-T Ethernet , RS-170, RS-232, RS-422

The IP-based JREAP application is referred to as JREAP-C. This allows any platform with access to the GIG and a small JREAP terminal to participate in the Link 16 network. MUOS allows aircrews access to the GIG in a BLOS capacity and is an ideal application of the JREAP-C protocol even with data rates limited to 16 kbps. As stated earlier, Link 16 data rates are usually transmitted at 27, 54, or 108 kbps but adequate LINK 16 data has been transmitted at lower rates as well. Rohde and Schwarz conducted testing of the JREAP-C protocol using HF radios with data rates not exceeding 8.5 kbps on good channels. The JRE system successfully passed multiple track data from the JRE gateway to the JRE enabled TacView. Various types of simulated TDL streams (Link 16, Link 11 and variable message format (VMF)) were converted into JREAP-C and transmitted over the HF link (Rhode & Schwarz, 2012). If viable Link 16 data can be passed via the JREAP-C protocol at data rates significantly under the 16 kbps threshold allocated to navy helicopters, then MUOS should have no problem supporting JREAP as well.

2. Video and Imagery

Video and still imagery were among the most desired data products according to pilots from the HSC community. The desire to see the landing zone prior to coming on station or the ability to compare visually, a target/contact of interest with an updated intelligence product is of great importance. Currently, the MH-60R is the most connected naval helicopter in service, but is still unable to receive full motion imagery data via Link 16 or Hawklink. They have the ability push both still and full motion video to the fleet but are lacking the capability to receive.

Looking to MUOS to provide full motion video capability is a stretch with maximum throughput of 384 kbps available if the platform is allocated an entire channel. The data required to stream video depends largely on the resolution used to display the video. We can compress video streams into smaller and smaller resolutions but they lose their ability to transmit the required information in a dark and vibrating cockpit. The standard web-based streaming resolution of 640X480 pixels requires approximately 600–700 kbps of information to be passed (Ozer, 2009). Many well-known media streaming companies such as Netflix and Hulu recommend a minimum of 1–2 Mbps for streaming of standard definition video content (Gonzalez, 2012).

Though full motion video is an unlikely candidate for the MUOS system, still imagery is still a needed capability within the helicopter community. Link 16 is now able to support still imagery between its MIDS-LVT terminals but is limited to line of sight environments. JREAP will be able to extend this capability within the Link 16 architecture, but with access to the GIG, a platform would not need the extra equipment associated with the JRE protocols.

The data requirements associated with still imagery vary according to the source of the photo and the post processing procedures added to the raw image. Based on the 16 kbps throughput allocated to Navy helicopters, Table 11 shows the time required to transmit a representative image to the helicopter. Lower data size FLIR imagery can be sent relatively quickly, but higher quality color photos require a much longer transmit time. The use of compression software would enhance the performance of sending still imagery across the network.

Table 11. Still Image Time to Load

Type	Resolution (pixel)	Size (Kb)	Time (sec)
Photo (b/w)	426 x 640	41.8	2.61
Photo (color)	640 x 480	182.0	11.38
FLIR (b/w)	600 x 600	51.7	3.23
FLIR (color)	640 x 480	91.6	5.73

Using MUOS to send imagery to aircrews located in remote locations will enhance overall mission effectiveness. An aircrew on strip alert to execute a helicopter visit, board, search and seizure (HVBSS) on a high value target would benefit from the latest intelligence to include any modifications to the structure of the vessel that would preclude an approach from a certain direction. Imagery passed from an ISR platform overhead will allow the aircrew to plan their approach prior to arriving on station and provide the helicopter assault force needed intelligence regarding the current state of the vessel.

3. Web Applications

Similar to other data applications associated with MUOS, the limited availability of throughput to the end user makes current web applications difficult to manage. The use of graphics and active content in order to make navigating a site easier only hinders users restricted in throughput.

In this section, NetBalancer was used to restrict the web browser, in this case Firefox, to a nominal speed of 16 kbps or 1.95 kBps as NetBalancer uses bytes instead of bits (see Appendix A). Three websites were chosen due to their relevance and use among naval aviators and access via unclassified networks. The three sites are listed below:

–Aviation Digital Data Service (ADDS) = http://aviationweather.gov/adds
–Defense Internet NOTAM Service = https://www.notams.faa.gov
–Baseops.net = http://www.baseops.net

The ADDS website provides different types of weather-based data and is used consistently among aircrews for flight planning. ADDS also provides RADAR coverage that includes loop displays of RADAR data. Multiple different links were accessed on this site and timed to get an indication of how long each area of the site would load at 16 kbps. The time it took to access different areas of the site are listed in Table 12. While not the fastest connection, the times were not unbearable and obviously loaded quicker once the standard graphics associated with the website were loaded from cache memory. The ADDS site was very usable if not operating in a fast pace or critical flight regime. One aspect of the website that was not usable due to the bandwidth restriction was the RADAR loop functions. These functions would not load given the limited throughput to the end user and would time out.

Table 12. ADDS Time to Load

Website	URL	Time to Load (sec)
ADDS Homepage	aviationweather.gov/adds	16.2
TAF/METAR	aviationweather.gov/adds/metars	8.88
TAF/METAR Search	aviationweather.gov/adds/metars?station_ids =knzy	1.5
RADAR Home	aviationweather.gov/adds/radar	1.5
RADAR Site (Mobile 32.32 kb)	radar.weather.gov/radar_lite.php?product=N CR&loop=no&rid=mob	74.1
RADAR Site (Vandenberg 20.85 kb)	radar.weather.gov/radar_lite.php?product=N CR&loop=no&rid=vbx	31.38

Notice to airmen (NOTAMS) are regularly distributed in a text format and require little data throughput. When accessing the Defense Internet NOTAM Service with a restricted throughput, access to the operational part of the site was very quick at 1.5 seconds. It did take an additional 35 seconds to load the background graphics associated with the site. Using the search function for three different airports returned a result in 33.74 seconds. The results of this query can be seen in Appendix B. Even with the reduced throughput, the NOTAM website was usable. This would be extremely helpful when needing to divert to a different airfield due to weather or mechanical problems.

The final website that was tested via a bandwidth restricted web browser was baseops.net. This website features general aviation information used for pre-flight planning, in-flight updates if connected, and post flight administrative functions. Initial access to the site loaded in 5.1 seconds with only two graphic elements continuing to load after.

Even when the throughput to the browser was restricted, web applications are still viable in non-critical stages of flight. Even better results may be achieved by leveraging low bandwidth or sites designed to work with mobile devices. Another way to increase the effectiveness is to disable the downloading of images, a common technique employed in the early days of the Internet with limited bandwidth connections. Military applications would also need to be tested on the SIPRnet, as that is the most common source of information accessed by aircrews when deployed.

4. Text and Email

Text- or chat-based applications are extensively used by operational units around the world. Chat applications allow users to quickly disseminate information but also keep a record of communications for later review. The ability of aircrews to text or chat with units on the ground, in the air, or even to headquarters located far from the terminal area will not eliminate battle field confusion but could lessen the impact of the fog of war.

Another advantage of text and chat applications is the small amount of data required to deliver the information. Typical alphanumeric text applications use a 40-line screen page with 80 characters per line. Each character uses 8 bits of information with a total screen requirement of 25.6 kilobits of data. If we run 25.6 kilobits across a 16 kbps network, the total time to transmit a screen of text would take 1.6 seconds (Kyas & Crawford, 2002). This type of performance would be acceptable to aircrews in a variety of situations.

Electronic mail (Email) is also ubiquitous among military operations as an easy and convenient way to send information to multiple individuals or units. The use of email in the naval helicopter community is limited to ground operations prior to arriving at the aircraft. With the advent of smart phones, some aircrews have been known to check email and texts during benign stages of flight. Currently this practice is not authorized except in emergency situations, as policies are not in place to ensure proper use of the technology. MUOS could allow integration of email into the avionics or multifunction displays enabling a new avenue of information transmission. The ability to use email to send more types of data than allowed by text or chat applications needs to be explored in order to capitalize on an emerging in-flight data path.

V. CONCLUSION

A. RESEARCH SUMMARY

The purpose of this thesis was to examine the history and current state of naval helicopter data networks and explore the benefits the addition of MUOS to the helicopter community may bring. By analyzing current capabilities of both aviation platforms and SATCOM systems, a baseline understanding was determined regarding network performance to the end user. With the addition of MUOS, possible future data requirements were highlighted to further define the capabilities and limitations provided to aircrews located in a BLOS environment.

B. FUTURE RESEARCH

The analysis in this report is only touching the surface of added capabilities provided by MUOS. Further investigation will be required as end user terminals become available. The likely areas of research include:

–Inflight testing of the MUOS system in conjunction with the AN/ARC-210 in a low altitude environment.

–Development of inflight specific applications for helicopter operations with a restricted data throughput design.

–Analyze the integration required to bring MUOS into the overall network centric operational environment.

C. CONCLUSION

Current helicopter networking capability has come along way since the introduction of the SH-2 Seasprite. Along with an increase in network capability is the dependence on that capability. The LAMPS Mk-III system provides exponentially better capability when data connectivity is established with the ship via Hawklink. The ability to share information and processing capabilities is a force multiplier for the Fleet. Now both the HSM and HSC communities are networked with the LINK 16 system and able to share and pass information via LOS, enabling a more efficient use of assets, ensuring mission success.

MUOS is just another tool to be used by network centric operators. Not only does MUOS increase legacy capacity over 16 times, it allows tactical users unmatched access to information previously unobtainable in a BLOS environment. Information once reserved for pre-mission planning can now be pushed via the Internet to small units on the move in real time.

Realizing the limitations imposed by MUOS both physically and through policy, the warfighter is now able to determine the best way to employ this new capability. Naval helicopter aircrews will enjoy greater access to SATCOM voice networks due to the increase in capacity and connectivity. An aircrew may call a supporting unit on the ground or communicate all the way to headquarters via a DSN line using the MUOS network.

The data capability provided by MUOS is the most exciting development when applying the network to helicopter operations. Access to the GIG anywhere in the world is a major benefit previously unavailable to aircrews. Even with data management policies restricting access to 16 kbps, there are viable ways to retrieve information via the Internet as seen in Chapter IV. Low bandwidth designed applications can increase the effectiveness of MUOS data transmissions for future operations. Text and chat clients are an ideal way to leverage MUOS in a limited bandwidth environment. They require very small amounts of data and convey a lot of information that is useable to aircrews inflight.

MUOS may not be able to provide the full motion video desired by many in the naval helicopter community, but it will bring a significant increase in SATCOM capacity and functions previously only used in ground operations (see Table 13). To employ the full capability of MUOS in the rotary wing environment further research needs to be conducted as end user terminals become available.

Table 13. Naval Helicopter Communications Overview

	UHF / VHF	SATCOM (DAMA)	SHF Hawklink	UHF Link 16	MUOS
Voice (LOS)	YES	YES	YES	YES	YES
Voice (BLOS)	-	YES	-	-	YES
Imagery	-	-	YES	YES	YES
Video	-	-	YES	-	-
Data	-	-	YES	YES	YES
Text	-	-	-	YES	YES
Email	-	-	-	-	YES
Web Applications	-	-	-	-	YES

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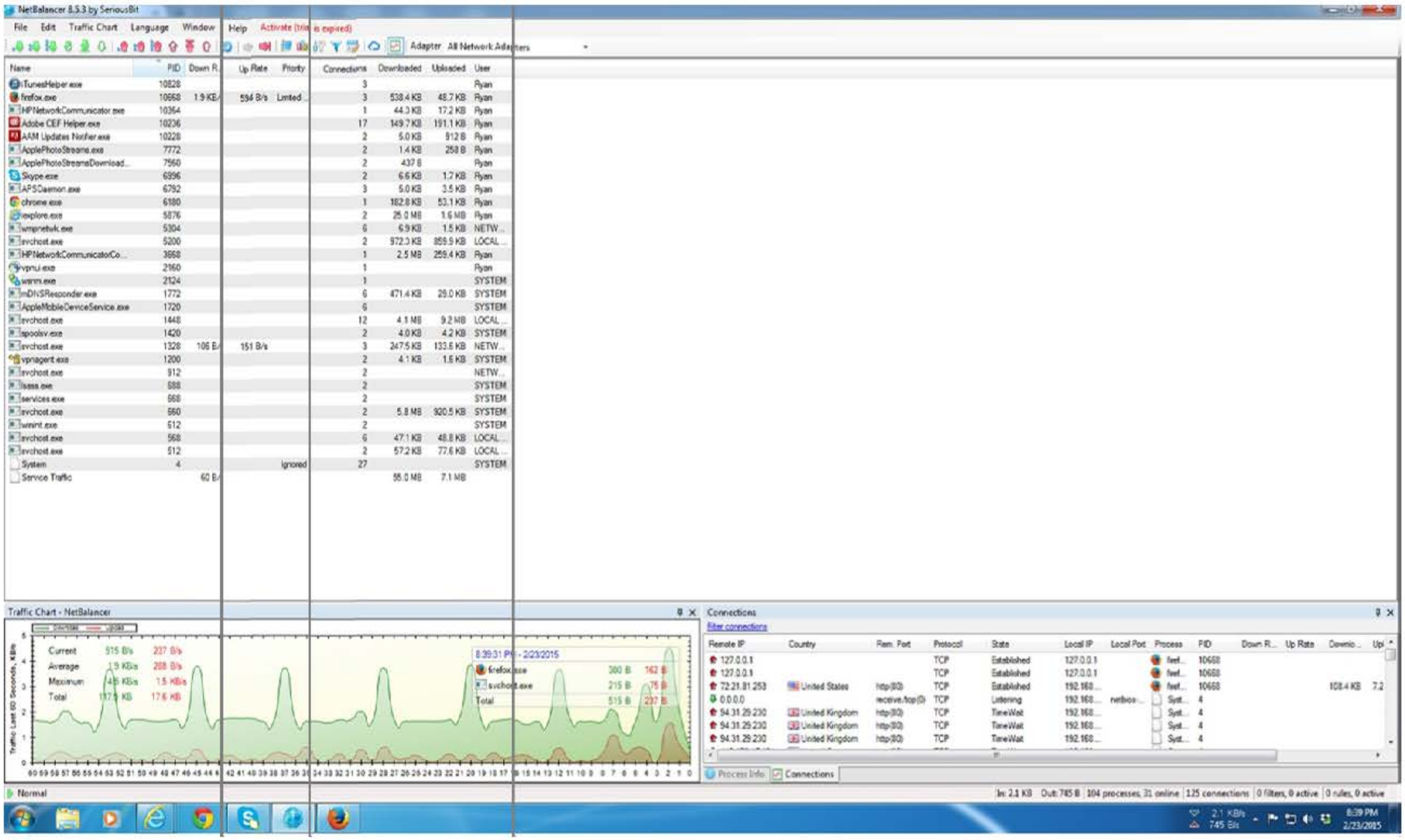
APPENDIX A. NETBALANCER

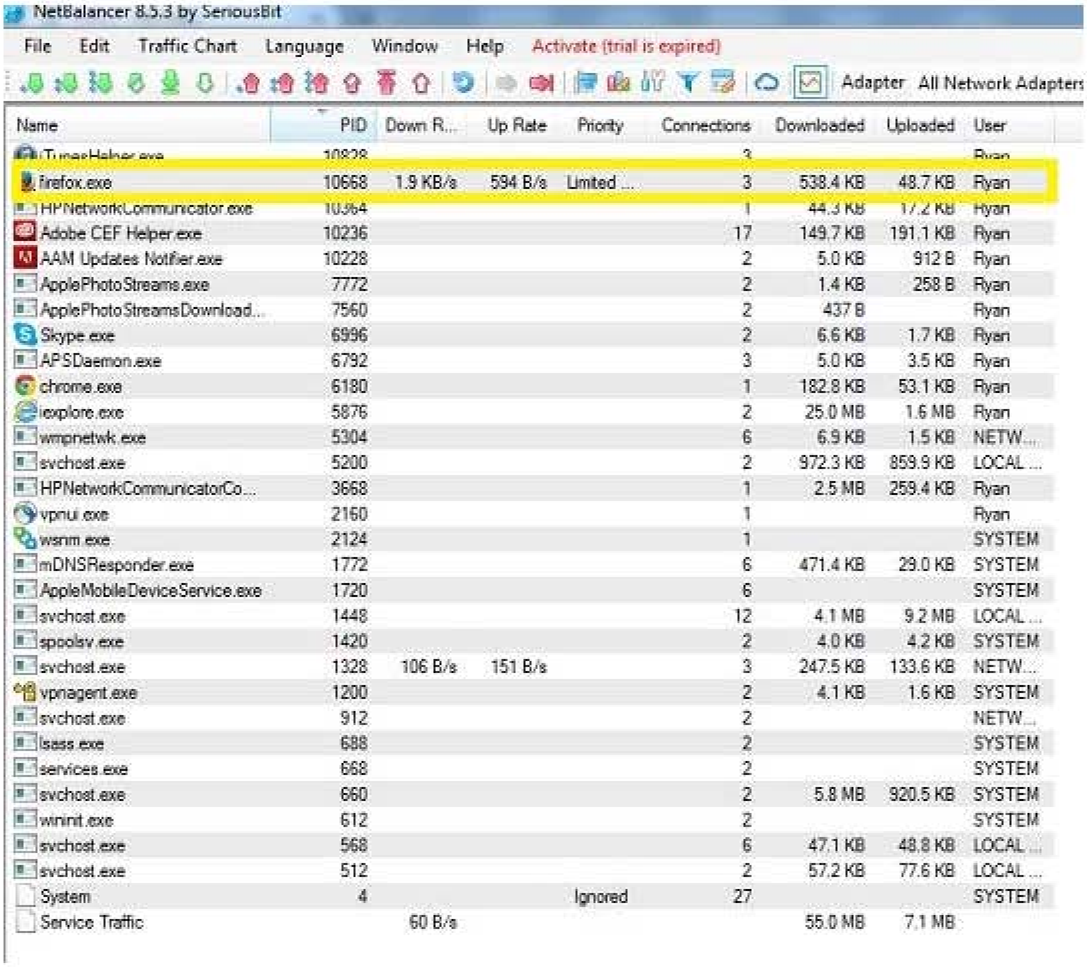
NetBalancer is a network traffic control and monitoring tool produced by seriousbit. This program was used to simulate the restrictive nature of the MUOS network for helicopter platforms. Helicopters are allocated 16 kbps data throughput as per the CONOPS proposed by PMW-146.

NetBalancer allows the user to restrict the data rate to various programs on a computer. For this research the limiting function was used to restrict internet browsers (Firefox), VOIP clients (Skype), and text/chat applications. This was done in order to determine the viability of MUOS using a low bandwidth data rate. Screen shots of NetBalancer are shown below:

NetBalancer can be obtained from the seriousbit website located at http://seriousbit.com/netbalancer.


NetBalancer 8.5.3 by SeriousBit
File Edit Traffic Chart Language Window Help
Adapter All Network Adapters
Traffic Chart - NetBalancer
Connections
Filter connections
Process Info
Connections
Normal

Screen Capture of NetBalancer (close up):


NetBalancer 8.5.3 by SeriousBit

File Edit Traffic Chart Language Window Help Activate (trial is expired)

Adapter All Network Adapters

Name	PID	Down R...	Up Rate	Priority	Connections	Downloaded	Uploaded	User
iTunesHelper.exe	10828				3			Ryan
firefox.exe	10668	1.9 KB/s	594 B/s	Limited ...	3	538.4 KB	48.7 KB	Ryan
HPNetworkCommunicator.exe	10364				1	44.3 KB	17.2 KB	Ryan
Adobe CEF Helper.exe	10236				17	149.7 KB	191.1 KB	Ryan
AAM Updates Notifier.exe	10228				2	5.0 KB	912 B	Ryan
ApplePhotoStreams.exe	7772				2	1.4 KB	258 B	Ryan
ApplePhotoStreamsDownload...	7560				2	437 B		Ryan
Skype.exe	6996				2	6.6 KB	1.7 KB	Ryan
APSDaemon.exe	6792				3	5.0 KB	3.5 KB	Ryan
chrome.exe	6180				1	182.8 KB	53.1 KB	Ryan
iexplore.exe	5876				2	25.0 MB	1.6 MB	Ryan
wmpnetwk.exe	5304				6	6.9 KB	1.5 KB	NETW...
svchost.exe	5200				2	972.3 KB	859.9 KB	LOCAL ...
HPNetworkCommunicatorCo...	3668				1	2.5 MB	259.4 KB	Ryan
vpnui.exe	2160				1			Ryan
wsnm.exe	2124				1			SYSTEM
mDNSResponder.exe	1772				6	471.4 KB	29.0 KB	SYSTEM
AppleMobileDeviceService.exe	1720				6			SYSTEM
svchost.exe	1448				12	4.1 MB	9.2 MB	LOCAL ...
spoolsv.exe	1420				2	4.0 KB	4.2 KB	SYSTEM
svchost.exe	1328	106 B/s	151 B/s		3	247.5 KB	133.6 KB	NETW...
vpnagent.exe	1200				2	4.1 KB	1.6 KB	SYSTEM
svchost.exe	912				2			NETW...
lsass.exe	688				2			SYSTEM
services.exe	668				2			SYSTEM
svchost.exe	660				2	5.8 MB	920.5 KB	SYSTEM
wininit.exe	612				2			SYSTEM
svchost.exe	568				6	47.1 KB	48.8 KB	LOCAL ...
svchost.exe	512				2	57.2 KB	77.6 KB	LOCAL ...
System	4			Ignored	27			SYSTEM
Service Traffic		60 B/s				55.0 MB	7.1 MB	

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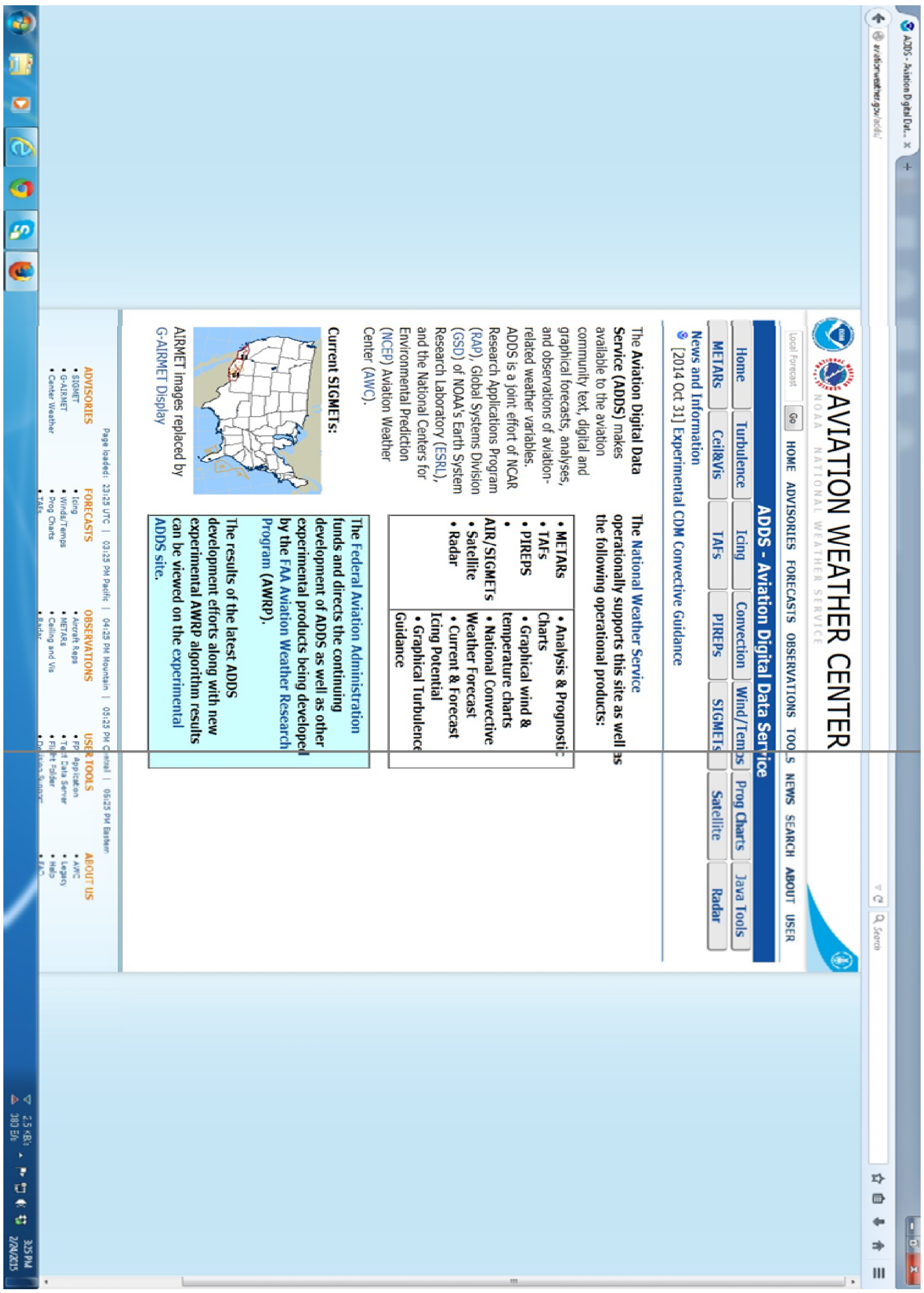
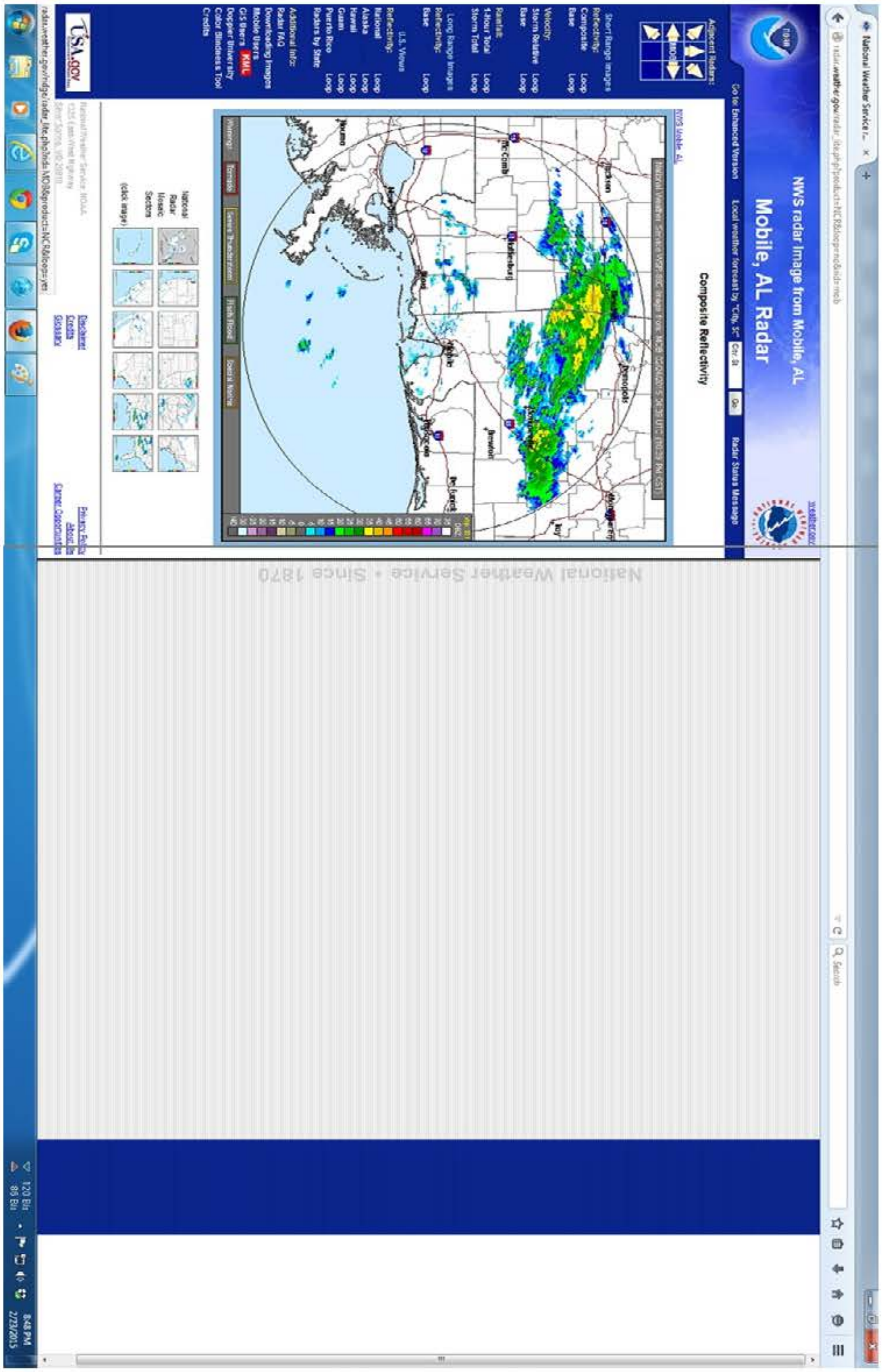
APPENDIX B. WEB APPLICATIONS

A. AVIATION DIGITAL DATA SERVICE (ADDS)

Screen Capture of ADDS Home Page:

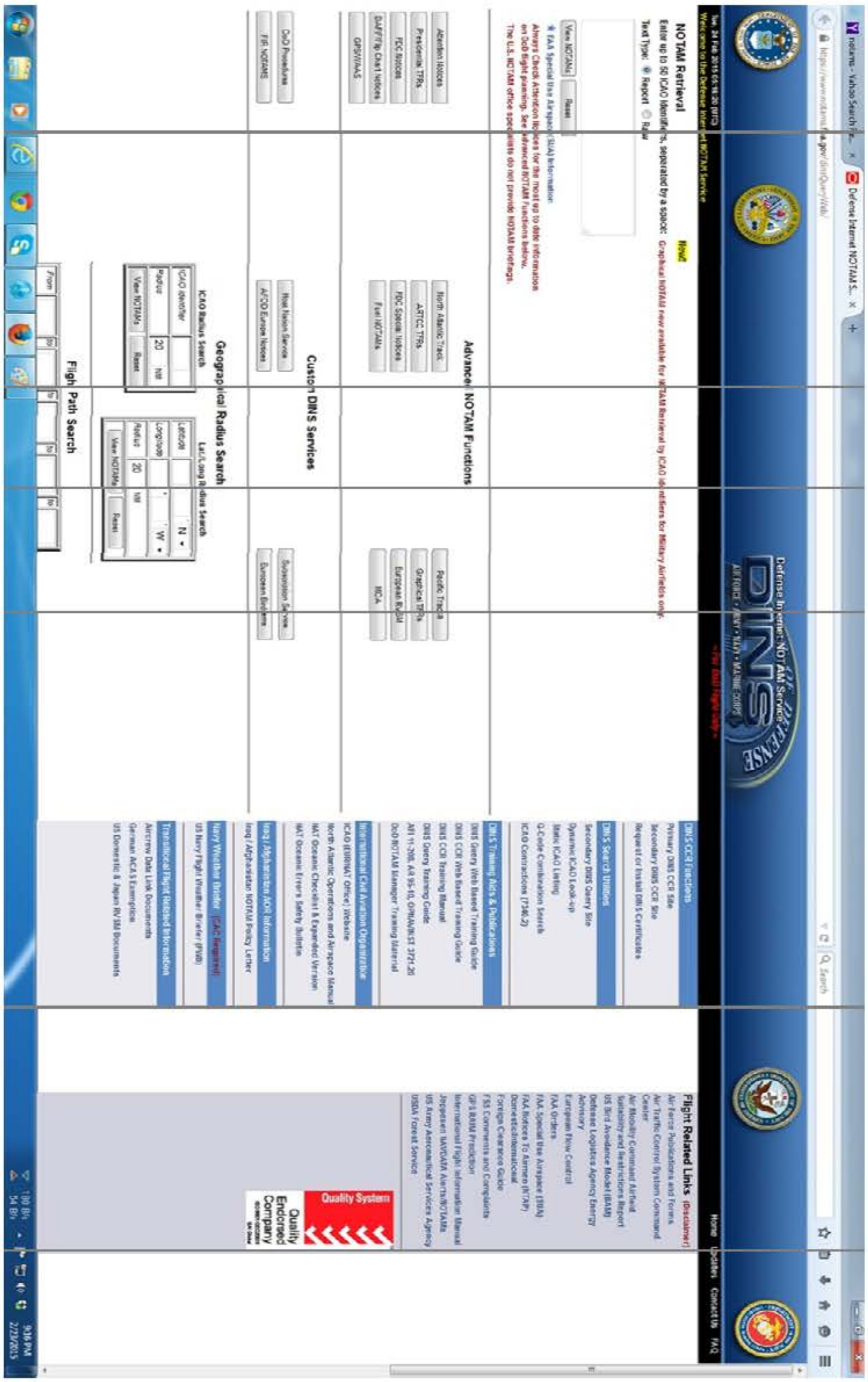


Screen Capture of ADDS RADAR page (Mobile):



B. DEFENSE INTERNET NOTAM SERVICE

Screen capture of NOTAM Home Page:



- NOTAM Search return for KNZY, KSAN, KBWI: 33.74 seconds

Sort By: Default Report Keyword Sort:
Locations:
KNZY, KSAN, KBWI
Data Current as of: Tue, 24 Feb 2015 05:17:00 GMT
KNZY NORTH ISLAND NAS /HALSEY FIELD/
M0071/15 - HAZARD 80' OBSTACLE AT THE APPROACH END OF RUNWAY 36
BOAT WASHED ASHORE
23FEB 1600Z - 25FEB 1600Z (23FEB 0800L - 25FEB 0800L)
N32 41' 2" W117 13' 8" (730' EAST OF CENTERLINE, 900' SOUTH OF RWY
36 APPROACH END) .
OBSTACLE IS UNLIT AND MARKED WITH SIGNAL FLAG.
PAD 12 CLSD UFN DUE TO 80' OBSTACLE LOCATED 900' SOUTH.
PAD 13 IS ALTERNATE NORDO PAD UNTIL OBSTACLE REMOVED. 24 FEB 01:10 2015 UNTIL
25 FEB 16:00 2015. CREATED: 24 FEB 01:04 2015
M0065/15 - AERODROME CLOSED FOR STATION FOD WALK 4 MAR, 1530-2000Z
(0730-1200L).
-TAXI CLEARANCE WILL NOT BE ISSUED AFTER 1515Z (0715(L)).
-NO CLOSED FIELD OPERATIONS.
-DO NOT START ENGINES, OPERATE AUXILIARY POWER UNITS, ENGINE TEST
CELLS OR
GSE WITHOUT ODO PERMISSION PRIOR TO 1000L (619-545-8233/4). 20 FEB 15:32 2015
UNTIL 04 MAR 20:01 2015. CREATED: 20 FEB 15:34 2015
M0061/15 - CHARLIE ARRESTING GEAR MARKERS (AGM) NOT ILLUMINATED UFN. 13 FEB
18:42 2015 UNTIL
12 MAR 23:59 2015. CREATED: 13 FEB 18:44 2015
M0041/15 - CORRECTION TO TACAN RWY 29 APCH CHART:
*WHEN ALS INOP, INCREASE CAT C & D VIS TO 1 AND 3/8 MILE. 29 JAN 21:11 2015
UNTIL 24 APR 23:59 2015. CREATED: 29 JAN 21:19 2015
L0004/15 - QUIET HOUR CONDITION 2 RESTRICTIONS, 26 FEB, 1800-1900Z
(1000-1100L), VIC HANGAR 1477.
-RWY 18/36, NO TKOF OR LANDING. NO LOC A OR B APPROACHES.
-RWY 29, NO TKOF FOR FIGHTER ATTACK ACFT.
-HELICOPTERS - NO PAD LANDINGS NORTH OF RWY 29 EXCEPT PAD 3. NO
TOWER TRANSITIONS.
-NO ACFT START UP/TAXI IN THE VIC OF HANGAR 1474/1477.
-NORTH WASH RACK CLSD.
-HOT SITE 1 AND 2 CLSD.
-HIGH POWER RUN UP NOT AUTH, INCLUDING NADEP.
QUIET HOURS RESTRICTIONS IN THIS MESSAGE DO NOT APPLY TO:
-ACFT IN DISTRESS.
-LAW ENFORCEMENT ACFT ON A SCRAMBLE DEPARTURE.
-ACFT WITH A HARD CVN OVERHEAD TIME.
-ACFT ON AN EMERGENCY DIVERT PROFILE TO NASNI FROM CVN.
-ACFT ON A BINGO PROFILE TO NASNI FROM UNITS OPERATING. 20 FEB 15:31 2015 UNTIL
26 FEB 19:01 2015. CREATED: 20 FEB 15:31 2015
KSAN SAN DIEGO INTL
02/053 (A0127/15) - NAV ILS RWY 27 U/S. 24 FEB 17:00 2015 UNTIL 24 FEB 21:00 2015.
CREATED: 23 FEB
23:36 2015
02/052 (A0126/15) - NAV ILS RWY 9 U/S. 24 FEB 17:00 2015 UNTIL 24 FEB 21:00 2015. CREATED:

23 FEB
23:34 2015
02/051 (A0125/15) - JLI NAV TACAN AZM U/S. 23 FEB 20:05 2015 UNTIL 04 MAR 21:00 2015
ESTIMATED. CREATED:
23 FEB 20:06 2015
02/050 (A0124/15) - SVC SFC MOVEMENT RADAR OUT OF SERVICE. 26 FEB 13:00 2015 UNTIL
26 FEB 14:15 2015.
CREATED: 23 FEB 18:56 2015
02/031 (A0099/15) - TWY G CLSD. 16 FEB 08:00 2015 UNTIL 25 JUN 14:00 2015. CREATED: 15 FEB
21:18
2015
01/020 (A0019/15) - NAV VOT CHECKPOINT AT TWY B4 COMMISSIONED. 08 JAN 19:44 2015
UNTIL 30 JUN 23:59
2015 ESTIMATED. CREATED: 08 JAN 19:44 2015
11/039 - NAV VOT UNUSABLE AT RWY 27 RUNUP AREA. 18 NOV 23:15 2014 UNTIL 01 JUN
22:14 2015
ESTIMATED. CREATED: 18 NOV 23:33 2014
08/026 (A0328/14) - APRON LANDMARK AVIATION RAMP PILOTS CONTACT GROUND
CONTROL PRIOR TO TAXI. 05 AUG 21:06 2014 UNTIL PERM. CREATED: 05 AUG 21:07 2014
11/009 - OBST CRANE 324411N1171059W (.2NM N APCH END RWY 27)
174FT (155FT AGL) FLAGGED AND LGTD. 05 NOV 14:53 2013 UNTIL 18 APR 23:59 2015.
CREATED: 05 NOV 14:53 2013
11/008 - OBST CRANE 324408N1171047W (.2NM N APCH END RWY 27)
174FT (155FT AGL) FLAGGED AND LGTD. 05 NOV 14:45 2013 UNTIL 18 APR 23:59 2015.
CREATED: 05 NOV 14:45 2013
FDC 5/9431 (A0077/15) - IAP SAN DIEGO INTL, SAN DIEGO, CA.
RNAV (GPS) RWY 27, AMDT 3B...
CIRCLING CAT C/D MDA 960/ HAA 943, VISIBILITY CAT C 2 3/4.
ALTERNATE MINIMUMS CAT C 960-2 3/4, REST REMAINS AS PUBLISHED.
TEMPORARY CRANE 600 MSL 2.42 NM SOUTHEAST OF SAN AIRPORT. 04 FEB 20:07 2015
UNTIL 03 AUG 20:07 2015 ESTIMATED. CREATED: 04 FEB 20:07 2015
FDC 5/9430 (A0076/15) - IAP SAN DIEGO INTL, SAN DIEGO, CA.
LOC RWY 27, AMDT 5B...
CIRCLING CAT C/D MDA 960/ HAA 943, VISIBILITY CAT C 2 3/4, CAT D 3.
ALTERNATE MINIMUMS CAT C 960-2 3/4, CAT D 960-3, REST REMAINS AS
PUBLISHED.
TEMPORARY CRANE 600 MSL 2.42 NM SOUTHEAST OF SAN AIRPORT. 04 FEB 20:07 2015
UNTIL 03 AUG 20:07 2015 ESTIMATED. CREATED: 04 FEB 20:07 2015
FDC 5/9429 (A0075/15) - IAP SAN DIEGO INTL, SAN DIEGO, CA.
ILS OR LOC RWY 9, AMDT 1C...
RNAV (GPS) RWY 9, ORIG-A...
CIRCLING CAT D MDA 960/ HAA 943, VISIBILITY CAT D 3.
ALTERNATE MINIMUMS CAT D 960-3, REST REMAINS AS PUBLISHED.
TEMPORARY CRANE 600 MSL 2.42 NM SOUTHEAST OF SAN AIRPORT. 04 FEB 20:07 2015
UNTIL 03 AUG 20:07 2015 ESTIMATED. CREATED: 04 FEB 20:07 2015
FDC 4/4626 (A0372/14) - IAP SAN DIEGO INTL, SAN DIEGO, CA.
ILS OR LOC RWY 9, AMDT 1C...
NOTE: HELICOPTER VISIBILITY REDUCTION BELOW 5000 RVR NOT
AUTHORIZED.
NOTE: CIRCLING NA N OF RWY 9-27. 12 SEP 15:41 2014 UNTIL 12 MAR 15:41 2015
ESTIMATED. CREATED: 12 SEP 15:43 2014
FDC 4/4625 (A0373/14) - IAP SAN DIEGO INTL, SAN DIEGO, CA.
RNAV (GPS) RWY 9, ORIG-A...
DISREGARD NOTE: VISIBILITY REDUCTION BY HELICOPTERS NA.
NOTE: HELICOPTER VISIBILITY REDUCTION BELOW 5000 RVR NOT

AUTHORIZED.
NOTE: CIRCLING NA N OF RWY 9-27. 12 SEP 15:41 2014 UNTIL 12 MAR 15:41 2015
ESTIMATED. CREATED: 12 SEP 15:43 2014
FDC 4/2323 (A0330/14) - IAP SAN DIEGO INTL, SAN DIEGO, CA.
RNAV (GPS) RWY 9, ORIG-A...
TERMINAL ROUTE RYAHH TO AZIME NA. 11 AUG 17:40 2014 UNTIL 11 FEB 17:40
2015 ESTIMATED. CREATED: 11 AUG 17:44 2014
KBWI BALTIMORE/WASHINGTON INTL THURGOOD MARSHALL
02/095 (A0311/15) - SVC TERMINAL AREA SURVEILLANCE RADAR/ SECONDARY
SURVEILLANCE RADAR U/S. 26 FEB 05:00 2015 UNTIL 26 FEB 08:00 2015. CREATED:
23 FEB 05:00 2015
02/094 (A0310/15) - SVC SFC MOVEMENT RADAR OUT OF SERVICE. 22 FEB 20:49 2015 UNTIL
28 FEB 23:59 2015.
CREATED: 22 FEB 20:49 2015
02/093 (A0309/15) - TWY R1 HOLDING POSITION SIGN NORTH SIDE BTN TWY R AND RWY
10/28 NOT STD. 22 FEB
18:12 2015 UNTIL 01 MAR 21:00 2015. CREATED: 22 FEB 18:13 2015
02/080 (A0289/15) - RWY 10 THR LGT OBSC. 21 FEB 15:33 2015 UNTIL 28 FEB 22:00 2015.
CREATED: 21 FEB
15:33 2015
02/078 (A0287/15) - TWY G HOLDING POSITION SIGN NORTH SIDE FOR RWY 10/28 NOT LGTD.
20 FEB 14:24 2015
UNTIL 20 MAR 22:00 2015. CREATED: 20 FEB 14:25 2015
02/077 (A0284/15) - TWY M EDGE LGT OUT OF SERVICE. 20 FEB 08:49 2015 UNTIL 27 FEB 17:00
2015. CREATED:
20 FEB 08:49 2015
02/076 (A0283/15) - TWY J EDGE LGT U/S. 20 FEB 08:43 2015 UNTIL 27 FEB 17:00 2015.
CREATED: 20 FEB
08:43 2015
02/075 (A0281/15) - RWY 15L/33R SURFACE MARKINGS NOT STD. 19 FEB 18:13 2015 UNTIL 19
FEB 18:00 2016.
CREATED: 19 FEB 18:13 2015
02/068 - OBST TOWER LGT (ASR 1044705) 391713.40N0764514.90W (7.8NM NNW BWI) 1231.0FT
(690.9FT
AGL) OUT OF SERVICE. 17 FEB 18:13 2015 UNTIL 04 MAR 18:13 2015. CREATED: 17 FEB
18:14 2015
02/067 (A0269/15) - TWY R1 HOLDING POSITION SIGN EAST SIDE BTN RWY 10/28 AND TWY R
LGT OUT OF
SERVICE.
17 FEB 17:42 2015 UNTIL 03 MAR 17:00 2015. CREATED: 17 FEB 17:42 2015
02/066 (A0268/15) - RWY 28 HOLDING POSITION SIGN FOR RWY 15R/33L LEFT SIDE
NOT LGTD. 17 FEB 17:21 2015 UNTIL 03 MAR 17:00 2015. CREATED: 17 FEB 17:21 2015
02/059 - OBST TOWER LGT (ASR 1255338) 391055.30N0764224.30W (1.8NM WNW BWI) 280.8FT
(90.9FT
AGL) OUT OF SERVICE. 16 FEB 08:17 2015 UNTIL 03 MAR 07:17 2015. CREATED: 16 FEB
08:17 2015
01/088 (A0139/15) - RWY 15R PAPI RIGHT SIDE COMMISSIONED. 23 JAN 18:35 2015 UNTIL
PERM. CREATED:
23 JAN 18:38 2015
01/051 (A0084/15) - TWY Y CLSD. 16 JAN 16:00 2015 UNTIL 31 AUG 16:00 2015. CREATED: 16
JAN 16:00
2015
01/026 - AIRSPACE SEE FDC 1/1155, 0/8326 ZDC 99.7 TFR. 08 JAN 17:51 2015 UNTIL 31 JAN
23:59 2016 ESTIMATED. CREATED: 08 JAN 17:51 2015
12/126 (A3016/14) - TWY D RUNUP PAD APCH END RWY 33L CLSD. 30 DEC 23:11 2014 UNTIL 30

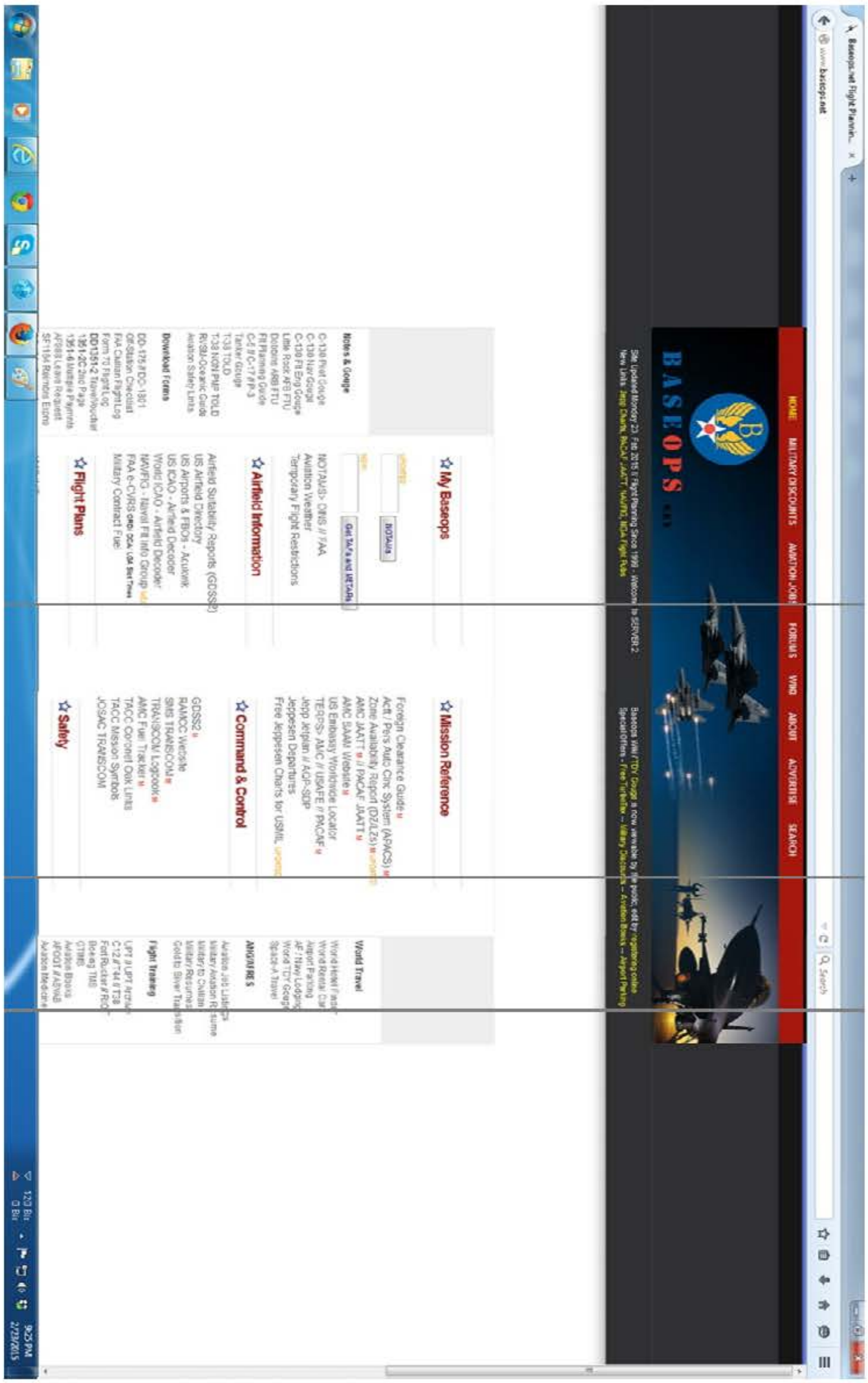
APR 04:00 2015.
CREATED: 30 DEC 23:11 2014
12/125 (A3013/14) - TWY E BTN RWY 10/28 AND TWY P CLSD. 30 DEC 22:30 2014 UNTIL 30 NOV 09:00 2015.
CREATED: 30 DEC 22:31 2014
12/124 (A3014/14) - TWY D BTN TWY D3 AND APCH END RWY 33L CLSD. 30 DEC 22:28 2014 UNTIL 30 APR 23:59
2015. CREATED: 30 DEC 22:28 2014
12/098 (A2972/14) - RWY 33L PAPI COMMISSIONED. 18 DEC 19:54 2014 UNTIL PERM. CREATED: 18 DEC 19:54
2014
12/057 (A2887/14) - RWY 15R/33L WIP CONST ADJ S END. 14 DEC 21:00 2014 UNTIL 12 APR 21:00 2015. CREATED:
13 DEC 02:57 2014
12/056 (A2885/14) - RWY 33L THR DISPLACED 500FT PRECISION MARKING. DECLARED DISTANCES: TORA
9500FT
TODA 9500FT ASDA 8800FT LDA 8300FT. 14 DEC 21:00 2014 UNTIL 12 APR 21:00 2015.
CREATED: 12 DEC 23:49 2014
12/055 (A2884/14) - RWY 15R THR DISPLACED 300FT PRECISION MARKING. DECLARED DISTANCES: TORA
9500FT
TODA 9500FT ASDA 8600FT LDA 8300FT. 14 DEC 21:00 2014 UNTIL 12 APR 21:00 2015.
CREATED: 12 DEC 23:38 2014
12/017 (A2818/14) - RWY 33L RVRT U/S. 03 DEC 16:58 2014 UNTIL 31 MAR 23:59 2015. CREATED: 03 DEC
16:58 2014
12/016 (A2817/14) - RWY 15R RVRR U/S. 03 DEC 16:56 2014 UNTIL 31 MAR 23:59 2015. CREATED: 03 DEC
16:56 2014
12/015 (A2816/14) - RWY 33L RVRR U/S. 03 DEC 16:53 2014 UNTIL 31 MAR 23:59 2015. CREATED: 03 DEC
16:53 2014
12/014 (A2815/14) - RWY 15R RVRT U/S. 03 DEC 16:51 2014 UNTIL 31 MAR 23:59 2015. CREATED: 03 DEC
16:51 2014
12/012 (A2810/14) - NAV ILS RWY 33L LOC/GP U/S. 03 DEC 16:17 2014 UNTIL 31 MAR 23:59 2015. CREATED:
03 DEC 16:17 2014
12/011 (A2809/14) - RWY 33L VASI U/S. 03 DEC 15:13 2014 UNTIL 31 MAR 23:59 2015. CREATED: 03 DEC
15:13 2014
12/010 (A2807/14) - RWY 33L ALS U/S. 03 DEC 15:09 2014 UNTIL 31 MAR 23:59 2015. CREATED: 03 DEC 15:09
2014
12/009 (A2806/14) - RWY 15R ALS U/S. 03 DEC 15:01 2014 UNTIL 31 MAR 23:59 2015. CREATED: 03 DEC 15:01
2014
12/008 (A2803/14) - NAV ILS RWY 15R LOC/GP U/S. 03 DEC 14:58 2014 UNTIL 31 MAR 23:59 2015. CREATED:
03 DEC 14:58 2014
02/040 (A0297/14) - BAL NAV TACAN AZM 029-039 RADIALS UNUSABLE. 10 FEB 21:54 2014 UNTIL 10 FEB 21:53
2015 ESTIMATED. CREATED: 10 FEB 21:54 2014
FDC 5/3240 (A0068/15) - IAP BALTIMORE/WASHINGTON INTL THURGOOD

MARSHALL, BALTIMORE, MD.
RNAV (GPS) Y RWY 15R, AMDT 2...
PROCEDURE NA. 13 JAN 13:48 2015 UNTIL 12 JUL 13:47 2015 ESTIMATED. CREATED: 13 JAN 13:49 2015
FDC 5/3125 (A0067/15) - IAP BALTIMORE/WASHINGTON INTL THURGOOD MARSHALL, BALTIMORE, MD.
ILS OR LOC RWY 33L, AMDT 11A...
RNAV (GPS) Y RWY 33L, AMDT 4...
RNAV (RNP) Z RWY 33L, AMDT 3...
VOR/DME RWY 33L, AMDT 3A...
CHART PROFILE NOTE: VGSI AND GLIDE SLOPE NOT COINCIDENT. 12 JAN 22:00 2015 UNTIL 11 JUL 22:00 2015 ESTIMATED. CREATED: 12 JAN 22:01 2015
FDC 4/2705 (A3010/14) - IAP BALTIMORE/WASHINGTON INTL THURGOOD MARSHALL, BALTIMORE, MD.
VOR/DME RWY 15L, AMDT 2A...
S-15L MDA 660/HAT 518 ALL CATS. VISIBILITY CAT A/B RVR 5500, CATS C 1 3/8.
CIRCLING CATS A/B/C MDA 700/HAA 554.
NOTE: NIGHT LANDING: CATS C/D RWY 15L NA.
NOTE: HELICOPTER VISIBILITY REDUCTION BELOW 1 SM NOT AUTHORIZED. 30 DEC 18:26 2014 UNTIL 28 JUN 18:26 2015 ESTIMATED. CREATED: 30 DEC 18:27 2014
FDC 4/1019 (A2969/14) - IAP BALTIMORE/WASHINGTON INTL THURGOOD MARSHALL, BALTIMORE, MD.
ILS RWY 15R, AMDT 15D...
PROCEDURE NA. 18 DEC 19:50 2014 UNTIL 16 JUN 19:49 2015 ESTIMATED. CREATED: 18 DEC 19:50 2014
FDC 4/1699 (A2774/14) - IAP BALTIMORE/WASHINGTON INTL THURGOOD MARSHALL, BALTIMORE, MD.
ILS OR LOC RWY 33L, AMDT 11A...
PROCEDURE NA. 01 DEC 21:11 2014 UNTIL 30 MAY 21:11 2015 ESTIMATED. CREATED: 01 DEC 21:13 2014
FDC 4/3747 (A2524/14) - IAP BALTIMORE/WASHINGTON INTL THURGOOD MARSHALL, BALTIMORE, MD.
VOR RWY 10, AMDT 17B...
VOR/DME RWY 33L, AMDT 3A...
PROCEDURE NA. 27 OCT 17:10 2014 UNTIL 25 APR 17:10 2015 ESTIMATED. CREATED: 27 OCT 17:10 2014
FDC 4/4271 (A2157/14) - SID BALTIMORE/WASHINGTON INTL THURGOOD MARSHALL,
BALTIMORE, MD.
PALEO THREE DEPARTURE...
DEPARTURE ROUTE DESCRIPTION: TAKEOFF RWY 4: CLIMB HEADING 044.19 TO 800 BEFORE TURNING LEFT. THENCE... TAKEOFF RWY 28: PROPS: CLIMB HEADING 285.22 TO 900 BEFORE TURNING RIGHT. THENCE... TAKEOFF RWY 33L: CLIMB HEADING 320.21 TO 2000 BEFORE TURNING RIGHT. THENCE...
...FOR VECTORS TO TRANSITION OR ASSIGNED ROUTE, EXPECT CLEARANCE TO FILED ALTITUDE TEN MINUTES AFTER DEPARTURE. TAKEOFF MINIMUMS: RWY 33L, STANDARD. RWY 4, 300-1 1/2 OR STANDARD WITH MINIMUM CLIMB OF 210 FEET PER NM TO 500, OR ALTERNATIVELY, WITH STANDARD TAKEOFF MINIMUMS AND A NORMAL 200 FT PER NM CLIMB GRADIENT, TAKEOFF MUST OCCUR NO LATER THAN 1300 FT PRIOR TO DER. RWY 33R, STANDARD WITH MINIMUM CLIMB OF 251 FEET PER NM TO 2000. NOTE: RADAR REQUIRED. NOTE: TAKEOFF RWY 28: JETS: DME REQUIRED. NOTE: RWY 10: BUILDING 52 FEET FROM DER, 319 FEET LEFT OF CENTERLINE, 13 FEET AGL/133 FEET MSL. NOTE: RWY 15R: TREES BEGINNING 1,144 FEET FROM DER, 740 FEET

END PART 1 OF 2. 11 SEP 16:11 2014 UNTIL 11 MAR 16:11 2015 ESTIMATED. CREATED: 11 SEP 16:15 2014
FDC 4/4271 (A2157/14) - SID
RIGHT OF CENTERLINE, UP TO 53 FEET AGL/172 FEET MSL. NOTE: RWY 15L: TREES BEGINNING 648 FEET FROM DER, 619 FEET LEFT OF CENTERLINE, UP TO 68 FEET AGL/167 FEET MSL. LIGHT ON POLE 921 FEET FROM DER, 618 FEET LEFT OF CENTERLINE, 62 FEET AGL/161 FEET MSL. NOTE: RWY 28: TREE 1,392 FEET FROM DER, 736 FEET LEFT OF CENTERLINE, 77 FEET AGL/176 FEET MSL. NOTE: RWY 33R: TREES BEGINNING 2,925 FEET FROM DER, 321 FEET LEFT OF CENTERLINE, UP TO 70 FEET AGL/289 FEET MSL. TREES BEGINNING 975 FEET FROM DER, 116 FEET RIGHT OF CENTERLINE, UP TO 83 FEET AGL/262 FEET MSL. ALL OTHER DATA REMAINS AS PUBLISHED.
END PART 2 OF 2. 11 SEP 16:11 2014 UNTIL 11 MAR 16:11 2015 ESTIMATED. CREATED: 11 SEP 16:15 2014
FDC 4/4270 (A2156/14) - SID BALTIMORE/WASHINGTON INTL THURGOOD MARSHALL,
BALTIMORE, MD.
SWANN THREE DEPARTURE...
DEPARTURE ROUTE DESCRIPTION: TAKEOFF RWY 4: CLIMB HEADING 044.19 TO 800 BEFORE TURNING LEFT. THENCE...TAKEOFF RWY 28: PROPS: CLIMB HEADING 285.22 TO 900 BEFORE TURNING RIGHT. THENCE...TAKEOFF RWY 33L: CLIMB HEADING 320.21 TO 2000 BEFORE TURNING RIGHT. THENCE...
...FOR VECTORS TO TRANSITION OR ASSIGNED ROUTE, EXPECT CLEARANCE TO FILED ALTITUDE TEN MINUTES AFTER DEPARTURE. TAKEOFF MINIMUMS: RWY 33L, STANDARD. RWY 4, 300-1 1/2 OR STANDARD WITH MINIMUM CLIMB OF 210 FEET PER NM TO 500, OR ALTERNATIVELY, WITH STANDARD TAKEOFF MINIMUMS AND A NORMAL 200 FT PER NM CLIMB GRADIENT, TAKEOFF MUST OCCUR NO LATER THAN 1300 FT PRIOR TO DER. RWY 33R, STANDARD WITH MINIMUM CLIMB OF 251 FEET PER NM TO 2000. NOTE: RADAR REQUIRED. NOTE: TAKEOFF RWY 28: JETS: DME REQUIRED. DUPONT TRANSITION NA EXCEPT FOR AIRCRAFT EQUIPPED WITH SUITABLE RNAV SYSTEM WITH GPS, DQO VORTAC R-233 FAILED FLIGHT INSPECTION. NOTE: RWY 10: BUILDING 52
END PART 1 OF 2. 11 SEP 16:11 2014 UNTIL 11 MAR 16:11 2015 ESTIMATED. CREATED: 11 SEP 16:12 2014
FDC 4/4270 (A2156/14) - SID
FEET FROM DER, 319 FEET LEFT OF CENTERLINE,13 FEET AGL/133 FEET MSL. NOTE: RWY 15R: TREES BEGINNING 1,144 FEET FROM DER, 740 FEET RIGHT OF CENTERLINE, UP TO 53 FEET AGL/172 FEET MSL. NOTE: RWY 15L: TREES BEGINNING 648 FEET FROM DER, 619 FEET LEFT OF CENTERLINE, UP TO 68 FEET AGL/167 FEET MSL. LIGHT ON POLE 921 FEET FROM DER, 618 FEET LEFT OF CENTERLINE, 62 FEET AGL/161 FEET MSL. NOTE: RWY 28: TREE 1,392 FEET FROM DER, 736 FEET LEFT OF CENTERLINE, 77 FEET AGL/176 FEET MSL. NOTE: RWY 33R: TREES BEGINNING 2,925 FEET FROM DER, 321 FEET LEFT OF CENTERLINE, UP TO 70 FEET AGL/289 FEET MSL. TREES BEGINNING 975 FEET FROM DER, 116 FEET RIGHT OF CENTERLINE, UP TO 83 FEET AGL/262 FEET MSL. ALL OTHER DATA REMAINS AS PUBLISHED.
END PART 2 OF 2. 11 SEP 16:11 2014 UNTIL 11 MAR 16:11 2015 ESTIMATED. CREATED: 11 SEP 16:12 2014
FDC 1/4717 (A1385/11) - FI/T STAR BALTIMORE/WASHINGTON INTL, BALTIMORE, MD, NOTTINGHAM SIX ARRIVAL... RADAR REQUIRED BETWEEN SABBI AND OTT DUE TO OTT VOR RESTRICTIONS. WIE UNTIL UFN. CREATED: 14 JUL 13:40 2011
Number of NOTAMs: 64 End of Report

C. BASEOPS.NET

Screen capture of the Home Page of baseops.net:



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